12
Physical Activity

SUMMARY

Physical activity promotes health and vigor. Cross-sectional data from a doubly labeled water database were used to define a recommended level of physical activity, based on the physical activity level (PAL) associated with a normal body mass index (BMI) range of 18.5 to 25 kg/m^2. In addition to the activities identified with a sedentary lifestyle, an average of 60 minutes of daily moderate intensity physical activity (e.g., walking/jogging at 3 to 4 miles/hour) or shorter periods of more vigorous exertion (e.g., jogging for 30 minutes at 5.5 miles/hour) was associated with a normal BMI and therefore is recommended for normal-weight individuals. This amount of physical activity leads to an "active" lifestyle, corresponding to a PAL greater than 1.6 (see Chapter 5). Because the Dietary Reference Intakes are provided for the general healthy population, recommended levels of physical activity for weight loss of obese individuals are not provided.

For children, the physical activity recommendation is also an average of 60 minutes of moderate intensity daily activity. Increasing the energy expenditure of physical activity (EEPA) needs to be considered in determining the energy intake to achieve energy balance in weight stable adults, and adequate growth and development in children (Chapter 5). Body weight serves as the ultimate indicator of adequate energy intake. Increasing EEPA, or maintaining an active lifestyle provides an important means for individuals to balance food energy intake with total energy expenditure.

BACKGROUND INFORMATION

A distinction is made between physical activity[1] and exercise;[2] the latter is considered more vigorous and leads to improvements in physical fitness.[3] In qualitative terms, exercise can be defined as activity sufficiently vigorous to raise breathing to a level where conversation is labored and sweating is noticeable on temperate days. As indicated in Table 5-10, cross-sectional data indicated that the average physical activity level (PAL) among adults participating in the doubly labeled water (DLW) studies included in the DLW Database (Appendix I) was about 1.7, reflecting physical activity habits equivalent to walking 5 to 7 miles/day at 3 to 4 mph, in addition to the activities required by a sedentary lifestyle. Also regular physical activity may improve mood by reducing depression and anxiety, thereby enhancing the quality of life. The beneficial outcomes of regular physical activity and exercise appear to pertain to persons of all ages, and both women and men of diverse ethnic groups.

Throughout history, balancing dietary energy intake and total energy expenditure (TEE) has been accomplished unconsciously by most individuals because of the large component of occupation-related energy expenditure. Today, despite common knowledge that regular physical activity is healthful, more than 60 percent of Americans are not regularly physically active, and 25 percent are not active at all (HHS, 1996). It seems reasonable to anticipate continuation of the current trend for reductions in occupational physical activity and other energy expending activities of daily life. If this is to be offset by deliberately increasing voluntary physical activity, it needs to be kept in mind that in previously sedentary individuals adding periods of mild to moderate intensity exercise can unconsciously be compensated for by reducing other activities during the remainder of the day, so that TEE may be less affected than expected (Epstein and Wing, 1980; van Dale et al., 1989). Hence, to increase physical activity and to thereby facilitate weight control, recreational activities and physical training programs need to add, and not substitute for, other physical activities of daily life.

The trend for decreased activity by adults is similar to trends seen in children who are less active in and out of school (HHS, 1996). As both lack of physical activity and obesity are now recognized as risk factors for

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[1]Physical activity—Bodily movement that is produced by the contraction of muscle and that substantially increases energy expenditure (HHS, 1996).

[2]Exercise (exercise training)—Planned structured and repetitive bodily movement done to promote or maintain one or more components of physical fitness.

[3]Physical fitness—A set of attributes that people have that relates to the ability to perform physical activity.

several chronic diseases, logic requires that activity recommendations accompany dietary recommendations.

History of Physical Activity Recommendations

United States

In 1953, Kraus and Hirschland (1953) alerted health and fitness professionals, the general public, and President Dwight D. Eisenhower to the relatively poor physical condition of American youth. Their paper and other events led to the formation of the President's Council on Youth Fitness (HHS, 1996). Under President John F. Kennedy, the council was renamed the President's Council on Physical Fitness, and in 1965 it established five levels of physical fitness for adult men and women. Subsequently, the word "sports" was added to the title of the organization, making it the President's Council on Physical Fitness and Sports (HHS, 1996).

Recognizing relationships among blood lipids, diet, and physical activity, the American Heart Association (AHA) issued in 1972 the first of its handbooks and statements on the use of endurance exercise training and exercise testing for the diagnosis and prevention of heart disease (AHA, 1972). In 1978, the American College of Sports Medicine (ACSM) issued its position statement on cardio-respiratory fitness and body composition titled "The Recommended Quantity and Quality of Exercise for Developing and Maintaining Fitness in Healthy Adults" (ACSM, 1978). Subsequently, ACSM issued a series of guidelines for exercise testing and prescription (ACSM, 1980).

In 1979, agencies of the federal government became involved when the United States Department of Heath, Education, and Welfare (DHEW) issued *Healthy People: The Surgeon General's Report on Health Promotion and Disease Prevention*, which recommended endurance exercise training (DHEW, 1979). In 1988, the U.S. Department of Heath and Human Services (HHS) issued *The Surgeon General's Report on Nutrition and Health*, which promoted endurance exercise as a means of weight control (HHS, 1988). Activities such as walking, jogging, and bicycling three times a week for 20 minutes were recommended.

That report was followed in 1990 by the U.S. Department of Agriculture (USDA)/Department of Health and Human Services *Dietary Guidelines for Americans*, which evaluated the role of activity in energy balance but did not offer specific exercise recommendations (USDA/HHS, 1990). In 1995, HHS issued the report *Healthy People 2000*, which listed health objectives for the nation, including an objective for physical activity and fitness (HHS, 1995). That same year, USDA and HHS updated *Dietary Guidelines for Americans* and recommended 30 minutes or more of moderate-intensity physical activity preferably on all days of the week (USDA/HHS, 1995). In 1996 the HHS report *Physical Activity and Health: A Report of the Surgeon General* was published and offered specific recommendations for physical activity: a minimum of 30 minutes of moderate intensity on most, if not all, days of the week.

The 2000 *Dietary Guidelines for Americans* recommends that adults accumulate at least 30 minutes and children 60 minutes of moderate physical activity most days of the week, preferably daily (USDA/HHS, 2000). In addition, that report recommended combining sensible eating with regular physical activity and acknowledged that physical activity and nutrition work together for better health. Physical activity and fitness objectives of *Healthy People 2010* seek to increase the proportion of Americans that engage in daily physical activity to improve health, fitness, and quality of life (HHS, 2000).

Canada

In Canada, similar recommendations have been proposed. An early initiative was the Toronto International Conference on Physical Activity and Cardiovascular Health in 1966. Toronto was also the site of the 1988 International Consensus Conference on Exercise, Fitness and Health. In 1992, coinciding with Canada's 125th birthday, the Second International Conference on Physical Activity, Fitness, and Health was held. That meeting resulted in publication of the report, *Physical Activity, Fitness, and Health* (Bouchard et al., 1994).

Most recently, in cooperation with Health Canada and the Canadian Society of Exercise Physiology, *Canada's Physical Activity Guide to Healthy Active Living* has been published (Health Canada, 1998). This guide describes the benefits of regular physical activity and makes specific recommendations to improve fitness and achieve particular health-related outcomes such as decreasing the risk of premature death from chronic diseases (heart disease, obesity, high blood pressure, type II diabetes, osteoporosis, stroke, colon cancer, and depression). The recommendations include 60 minutes of "light effort" exercises (e.g., light walking, easy gardening), 30 to 60 minutes of "moderate effort" exercises (e.g., brisk walking, biking, swimming, water aerobics, leaf raking), or 20 to 30 minutes of "vigorous effort" exercises (e.g., aerobics, jogging, hockey, fast swimming, fast dancing, basketball). For moderate and vigorous activities, the Canadian recommendations are for 4 or more days per week and also include participation in flexibility activities (4–7 days per week) and strength activities (4–7 days per week).

PHYSICAL ACTIVITY LEVEL AND ENERGY BALANCE

Aside from dietary energy intake, energy expenditure of physical activity (EEPA) is the variable that a person can control, in contrast to age, height, and gender (Chapter 5). Energy expenditure can rise many times over resting rates during exercise, and the effects of an exercise bout on energy expenditure persist for hours, if not a day or longer (Benedict and Cathcart, 1913; Van Zant, 1992). Thus, changing activity level can have major impacts on total energy expenditure (TEE) and on energy balance. Further, exercise does not automatically increase appetite and energy intake in direct proportion to activity-related changes in energy expenditure (Blundell and King, 1998; Hubert et al., 1998; King et al., 1997). In humans and other mammals, energy intake is closely related to physical activity level when body mass is in the ideal range, but too little or too much exercise may disrupt hypothalamic and other mechanisms that regulate body mass (Mayer et al., 1954, 1956).

Impact of Physical Activity on Energy Expenditure and on PAL

Metabolic Equivalents (METs)

The impact of various physical activities is often described and compared in terms of METs (i.e., multiples of an individual's resting oxygen uptake), and one MET is defined as a rate of oxygen (O_2) consumption of 3.5 ml/kg/min in adults. Taking the oxygen energy equivalent of 5 kcal/L consumed, this corresponds to 0.0175 kcal/minute/kg (3.5 mL/min/kg $\times$ 0.005 kcal/mL). A rate of energy expenditure of 1.0 MET thus corresponds to 1.2 kcal/min in a man weighing 70 kg (0.0175 kcal/kg/minute $\times$ 70 kg) and to 1.0 kcal/minute in a woman weighing 57 kg (0.0175 kcal/kg/min $\times$ 57 kg) based on the reference body weights for adults in Table 1-1.

Knowing the intensity of a type of physical activity in terms of METs (see Table 12-1 for the METs for various activities) allows a simple assessment of its impact on the energy expended while the activity is performed (number of METs $\times$ minutes $\times$ 0.0175 kcal/kg/minute). However, as mentioned in Chapter 5, the increase in daily energy expenditure is somewhat greater because exercise induces an additional small increase in expenditure for some time after the exertion itself has been completed. This "excess post-exercise oxygen consumption" (EPOC) (Gaesser and Brooks, 1984) depends on exercise intensity and duration as well as other factors, such as the types and durations of activities in normal living; EPOC has been estimated at about 15 percent of the increment in expenditure that occurs during the exertion itself (Bahr et al., 1987). The thermic effect of food (TEF), which needs to be consumed to cover the expenditure associated

TABLE 12-1 Intensity and Impact of Various Activities on Physical Activity Level (PAL) in Adults[a]

Activity	Metabolic Equivalents (METs)[b]	ΔPAL/10 min[c]	ΔPAL/h[c]
Leisure			
Mild			
Billiards	2.4	0.013	0.08
Canoeing (leisurely)	2.5	0.014	0.09
Dancing (ballroom)	2.9	0.018	0.11
Golf (with cart)	2.5	0.014	0.09
Horseback riding (walking)	2.3	0.012	0.07
Playing			
Accordion	1.8	0.008	0.05
Cello	2.3	0.012	0.07
Flute	2.0	0.010	0.06
Piano	2.3	0.012	0.07
Violin	2.5	0.014	0.09
Volleyball (noncompetitive)	2.9	0.018	0.11
Walking (2 mph)	2.5	0.014	0.09
Moderate			
Calisthenics (no weight)	4.0	0.029	0.17
Cycling (leisurely)	3.5	0.024	0.14
Golf (without cart)	4.4	0.032	0.19
Swimming (slow)	4.5	0.033	0.20
Walking (3 mph)	3.3	0.022	0.13
Walking (4 mph)	4.5	0.033	0.20
Vigorous			
Chopping wood	4.9	0.037	0.22
Climbing hills (no load)	6.9	0.056	0.34
Climbing hills (5-kg load)	7.4	0.061	0.37
Cycling (moderately)	5.7	0.045	0.27
Dancing			
Aerobic or ballet	6.0	0.048	0.29
Ballroom (fast) or square	5.5	0.043	0.26
Jogging (10-min miles)	10.2	0.088	0.53
Rope skipping	12.0	0.105	0.63
Skating			
Ice	5.5	0.043	0.26
Roller	6.5	0.052	0.31
Skiing (water or downhill)	6.8	0.055	0.33
Squash	12.1	0.106	0.63
Surfing	6.0	0.048	0.29
Swimming	7.0	0.057	0.34
Tennis (doubles)	5.0	0.038	0.23
Walking (5 mph)	8.0	0.067	0.40

continued

TABLE 12-1 Continued

Activity	Metabolic Equivalents (METs)[b]	ΔPAL/10 min[c]	ΔPAL/h[c]
Activities of daily living			
Gardening (no lifting)	4.4	0.032	0.19
Household tasks, moderate effort	3.5	0.024	0.14
Lifting items continuously	4.0	0.029	0.17
Light activity while sitting	1.5	0.005	0.03
Loading/unloading car	3.0	0.019	0.11
Lying quietly	1.0	0.000	0.00
Mopping	3.5	0.024	0.14
Mowing lawn (power mower)	4.5	0.033	0.20
Raking lawn	4.0	0.029	0.17
Riding in a vehicle	1.0	0.000	0.00
Sitting	0.0	0.000	0.00
Taking out trash	3.0	0.019	0.11
Vacuuming	3.5	0.024	0.14
Walking the dog	3.0	0.019	0.11
Walking from house to car or bus	2.5	0.014	0.09
Watering plants	2.5	0.014	0.09

[a] PAL is the physical activity level that is the ratio of the total energy expenditure to the basal energy expenditure.
[b] METs are multiples of an individual's resting oxygen uptakes, defined as the rate of oxygen (O_2) consumption of 3.5 mL of O_2/min/kg body weight in adults.
[c] In the PAL shown here, an allowance has been made to include the delayed effect of physical activity in causing excess postexercise O_2 consumption and the dissipation of some of the food energy consumed through the thermic effect of food.
SOURCE: Adapted from Fletcher et al. (2001).

with a given activity, must also be taken into account. The TEF dissipates about 10 percent of the food energy consumed. The impact of a given activity on daily energy expenditure under conditions of energy balance thus includes the intensity of the physical activity in terms of METS, the EPOC, and the TEF and expressed as:

$$\text{\# of METs} \times \text{min} \times 0.022 \text{ kcal/kg/min} \times \text{kg body weight},$$

where 0.022 kcal/kg/min = 0.0175 kcal/kg/min × 1.15 percent (EPOC) ÷ 0.9 percent (TEF).

Bijnen and coworkers (1998) found that activities with METs greater than 4 are more effective than less intensive activities in reducing cardiovascular mortality. A rate of energy expenditure of 4.5 METs corresponds to the upper boundary for moderate activities (Table 12-1) and elicits an exertion that falls into the upper range of the percent of Vo_2max considered to reflect light physical activity intensity for 20- to 39-year-old adults, but falls into the lower range of moderate intensities in 40- to 64-year-old adults (Fletcher et al., 2001). A rate of exertion of 4.5 METs is reached, for example, by walking at a speed of 4 mph (Table 12-1).

Physical Activity Level (PAL)

While METs describe activity intensities relative to a resting metabolic rate (RMR), the physical activity level (PAL) is defined as the ratio of total energy expenditure (TEE) to basal energy expenditure (BEE). Thus, the actual impact on PAL depends to some extent on body size and age, as these are determinants of the BEE (Figure 12-1). The impact of these factors can be judged by examining the ratio of MET (extrapolated to 24 hours) to BEE. It is noteworthy that the errors that this introduces in the calculation of PAL values, at least over the normal range of body weights, is of minor importance in comparison to the very large uncertainties generally inherent in the assessment of the duration and intensity of physical activities in individuals and populations.

For a typical 30-year-old reference man and woman 1.77 m and 1.63 m in height and weighing 70 kg and 57 kg (Chapter 1, Table 1-1), BEEs are 1,684 and 1,312 kcal/day, respectively (calculated from the predictive BEE equations in Chapter 5. These correspond to 0.95 and 0.91 times the 1,764 and 1,436 kcal/day obtained by extrapolating a rate of 1.0 MET[4] to 24 hours for reference men and women (1,764 kcal/day = 1 MET × 1,440 min × 0.0175 kcal/kg/min × 70 kg and 1,436 kcal/day = 1 MET × 1,440 min × 0.0175 kcal/kg/min × 57 kg). The following equations, derived for reference body weights of 70 kg for men and 57 kg for women, were utilized to determine the change in PAL for each of the activities in Table 12-1.

$$\text{Men:}\quad \Delta PAL = (\#\text{ of METs} - 1) \times 1.34 \times (\text{min}/1{,}440\text{ min}),$$

where 1.34 = 1.15 percent (EPOC) ÷ 0.9 percent (TEF) ÷ 0.95 percent.[5]

$$\text{Women:}\quad \Delta PAL = (\#\text{ of METs} - 1) \times 1.42 \times (\text{min}/1{,}440\text{ min}),$$

where 1.42 = 1.15 percent (EPOC) ÷ 0.9 percent (TEF) ÷ 0.91.[5]

[4]Defined as 0.0175 kcal/kg/min.
[5]Correction to cover EPOC and TEF.

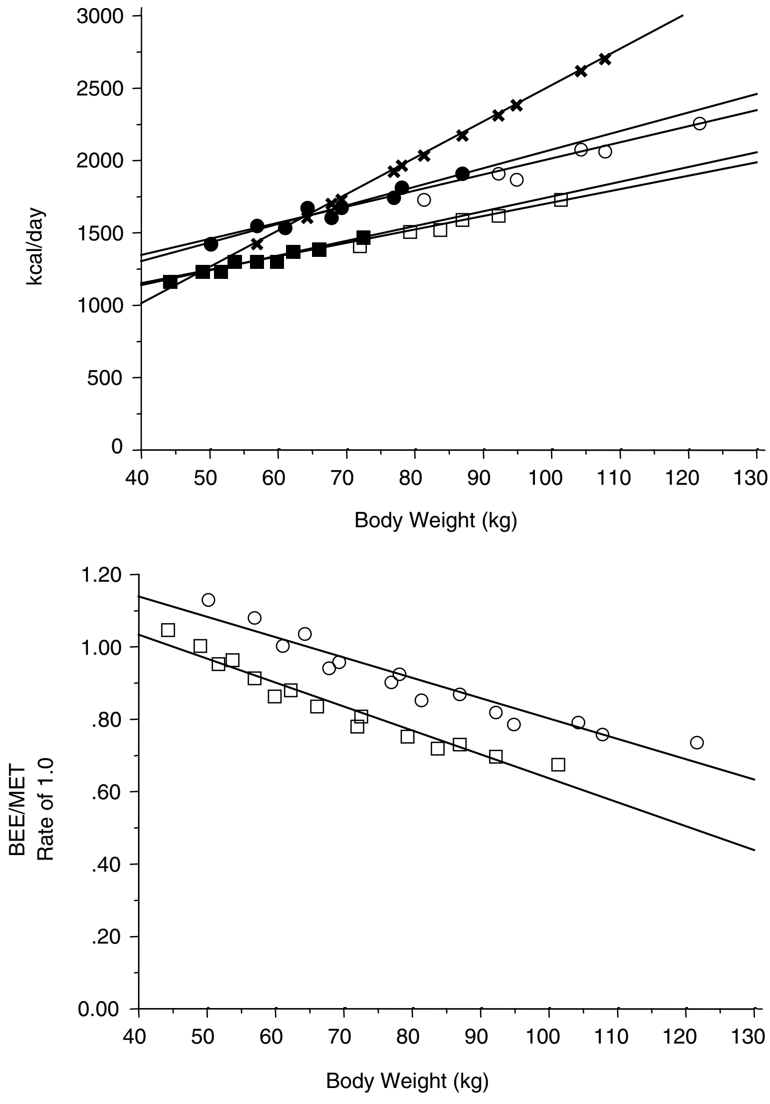

FIGURE 12-1 Relationship of basal energy expenditure (BEE), metabolic equivalents rate and body weight in 30-year-old adults. The upper panel shows the impact of body weight on BEE in men (○) and women (□) and on a MET-rate of 1.0 (×) extrapolated to 24 h. Points with body mass indexes (BMIs) from 18.5 up to 25 kg/m^2 are filled in. The lower panel shows the ratio of BEE divided by an MET rate of 1.0 for a given body weight for men (○) with reference heights of 1.75 m or reference height ± 1 standard deviation (i.e., 1.64 or 1.86 m), and for women (□) with reference heights of 1.62 m or reference height ± 1 standard deviation (i.e., 1.55 or 1.70 m), and BMI of 18.5, 22.5 (men) or 21.5 (women), 25, 30, and 35 kg/m^2.

The coefficients given in Table 12-1 can then be used to arrive at an estimate of an individual's PAL by cumulating the effects of the various activities performed on the basis of their duration and intensities (see below, "Physical Activity for Adults").

Because it is the most significant physical activity in the life of most individuals, walking/jogging is taken as the reference activity, and the impact of other activities can be considered in terms of exertions equivalent to walking/jogging, to the extent that these activities are weight bearing and hence involve costs proportional to body weight. The effect of walking/jogging on energy expenditure at various speeds is given in Table 12-1 in terms of METs and is also shown in the upper panel of Figure 12-2. The middle panel describes the energy expended in kcal/hour for walking or jogging at various speeds by individuals weighing 70 or 57 kg (the reference body weights for men and women, respectively from Table 1-1. The figure's lower panel describes the total cost of walking or jogging one mile at various speeds, including the increments in energy expenditure above the resting rate during and after walking or jogging plus a commensurate increase in TEF. The energy expended per mile walked or jogged is essentially constant at speeds ranging from 2 to 4 miles/hour (1 kcal/mile/kg for a man [70 kcal/mile/70 kg] to 1.1 kcal/mile/kg for a woman [65 kcal/mile/57 kg], or approximately 1.1 kcal/mile/kg body weight; lower panel, Figure 12-2), but increases progressively at higher speeds.

According to the formulas shown above, walking at a speed of 4 mph (4.5 METs, upper panel, Figure 12-2) for 60 minutes causes an increase in the daily ΔPAL of 0.195 ([4.5 METs – 1] $\times$ 1.34 $\times$ 60 min/1,440 min) in men and 0.204 ([4.5 METs – 1] $\times$ 1.42 $\times$ 60 min/1,440 min) in women, or a ΔPAL of approximately 0.20 as given in Table 12-1. Walking or jogging at speeds of 4.5 mph raises the metabolic rate to 6 METS (upper panel, Figure 12-2), increasing the impact on changing the daily PAL by half to 0.30 for sixty minutes (ΔPAL in men = [6 METs – 1] $\times$ 1.34 $\times$ 60 min/1,440 min = 0.279, ΔPAL in women = [6 METs – 1] $\times$ 1.42 $\times$ 60 min/1,440 min = 0.296). Indeed, walking or jogging to cover 4.5 miles in 60 minutes, at a cost of 107 kcal/mile (lower panel, Figure 12-2) or 1.53 kcal/mile/kg (107 kcal/mile $\div$ 70 kg) in men, or performing some equally demanding activity for 60 minutes, will cause an increase in PAL of approximately 0.30.

Impact of Body Weight on Energy Expenditure

The impact of body weight on energy expenditure while walking at various speeds is illustrated in Figure 12-3, while Figure 12-4 describes how body weight affects the total increase in energy expenditure caused by

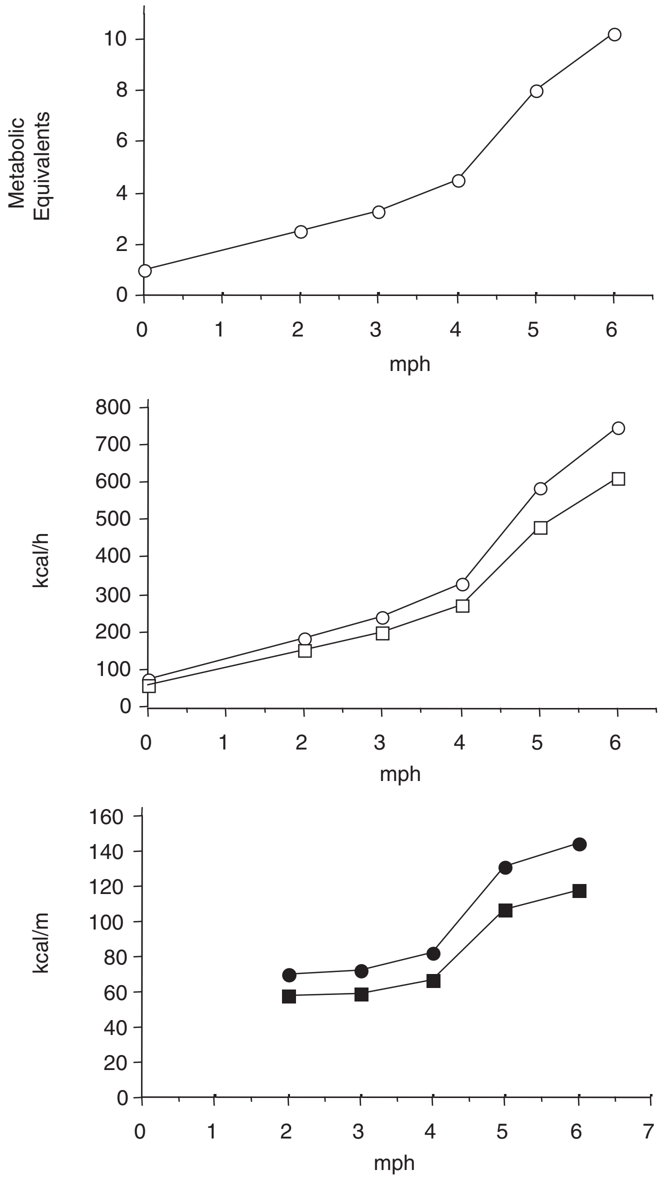

FIGURE 12-2 Relationships of energy expenditure and walking/jogging speeds. The upper panel shows the rate of energy expenditure as a function of walking/jogging speed. The middle panel shows the energy expended by a 70-kg man (○) and by a 57-kg woman (□) while walking/jogging 1 h at various speeds. The lower panel shows the increase in daily energy expenditure induced by walking/jogging 1 m at various speeds for a 70-kg man (●) and a 57-kg woman (■).

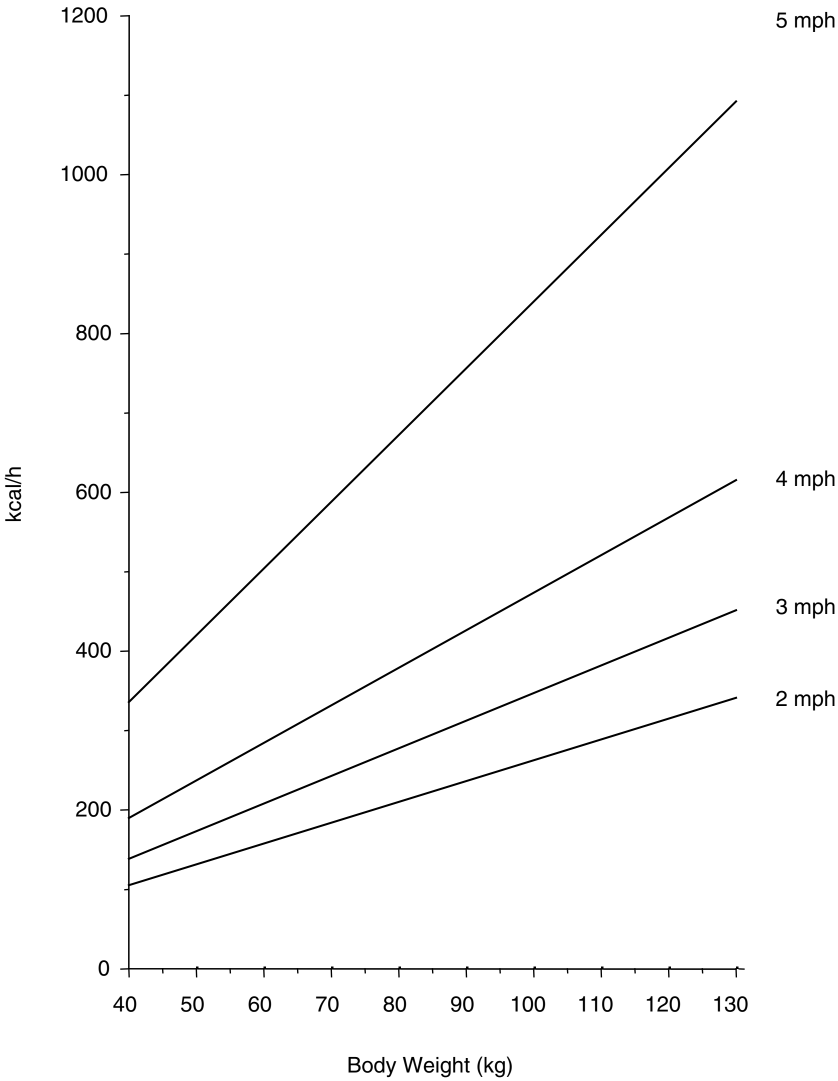

FIGURE 12-3 Impact of body weight on energy expenditure while walking at speeds of 2, 3, 4, or 5 mph.

walking one mile at various speeds. Figures 12-5 for men and 12-6 for women show how body weight influences how far and for how many minutes adults must walk at speeds of 2, 3, 4, or 5 mph (or to engage in activities rated as MET = 2.5, 3.3, 4.5, or 8.0) to raise the PAL level by 0.10. These figures also describe the effect of more demanding physical activity,

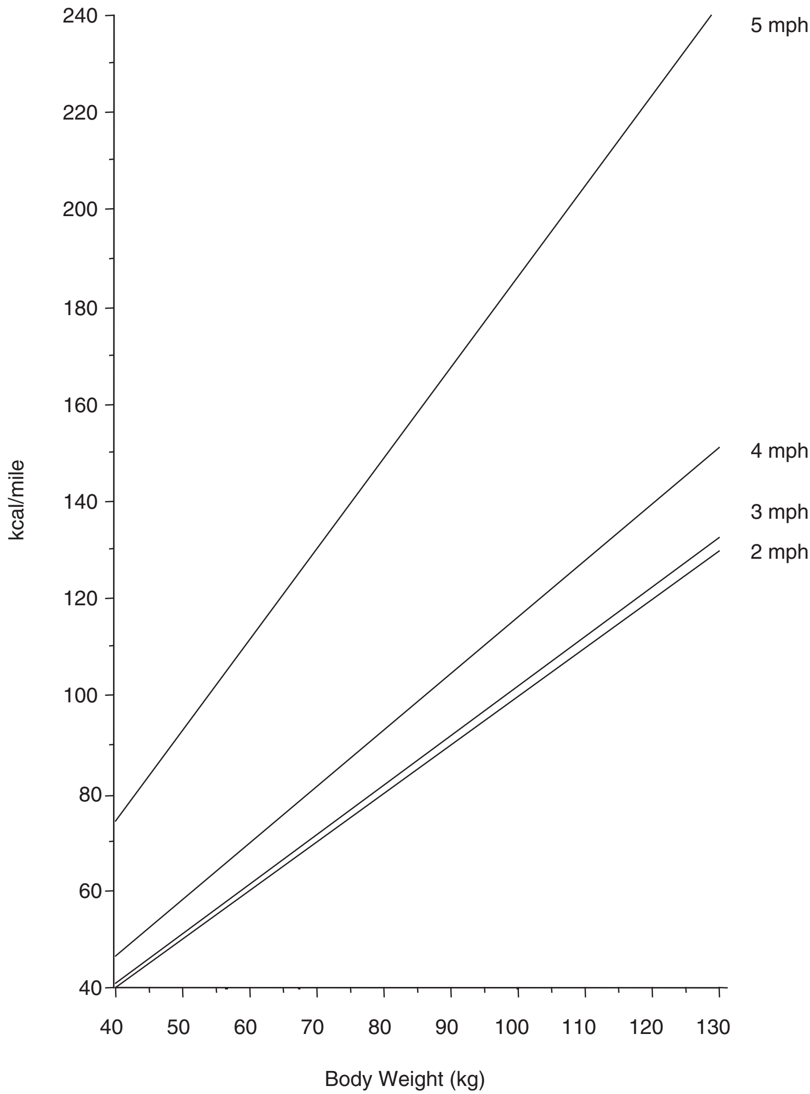

FIGURE 12-4 Impact of body weight on energy cost of walking 1 mile at speeds of 2, 3, 4, or 5 mph in men and women.

such as running at speeds of 6 or 8 mph, corresponding to exertions at 10.2 or 13.5 METs. While the effect on TEE/miles covered does not increase substantially as fast walking (5 mph) changes to jogging (6 mph) and running (8 mph) (upper panels of Figures 12-5 and 12-6), the time required for a given impact on PAL is reduced. This illustrates that high

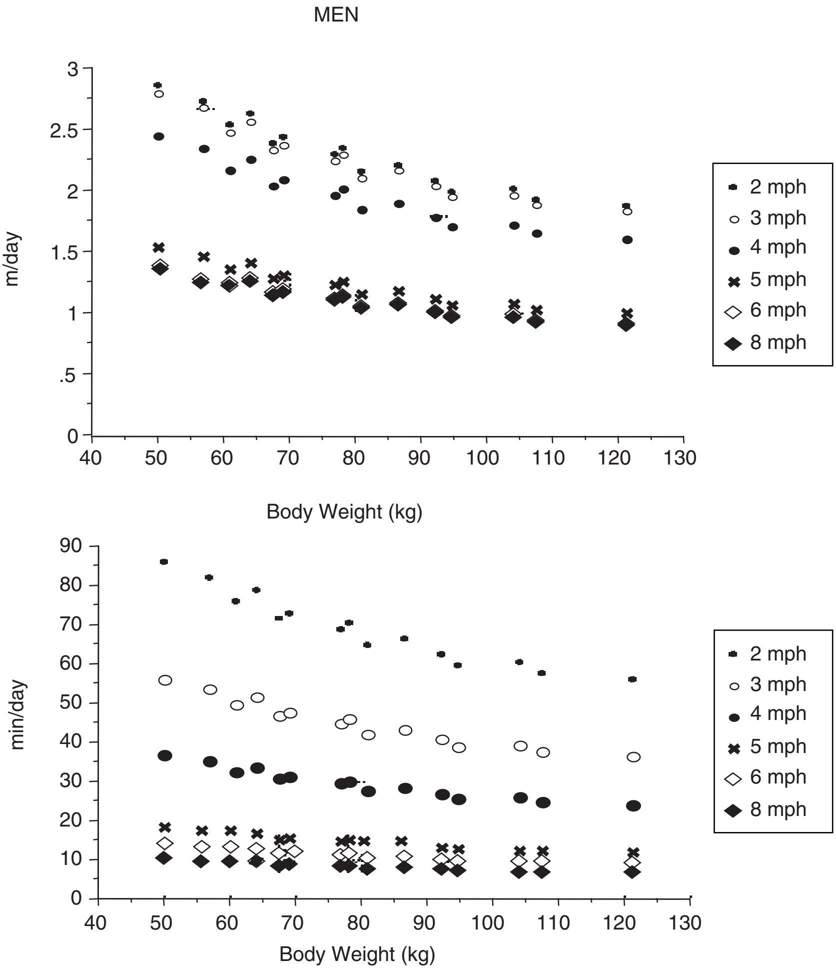

FIGURE 12-5 Distance to cover per day for men to raise physical activity level (PAL) value by 0.10 while walking or running at various speeds (upper panel) and time required to do so (lower panel). The points shown are for men with reference heights of 1.75 m or reference heights ± 1 standard deviation (i.e., 1.64 m or 1.86 m) and body mass index of 18.5, 22.5, 25, 30, or 35 kg/m^2. Energy expenditures while walking or running at speeds of 2, 3, 4, 5, or 8 mph are 2.5, 3.3, 4.5, 8.0, 10.2, and 13.5 metabolic equivalents (METs), respectively (Fletcher et al., 2001). The impact on ΔPAL was calculated as (MET – 1.0) × minutes × 1.15 ÷ 0.9 (where 1.15 accounts for excess [~15%] post-exercise oxygen consumption [Bahr et al., 1987] and 0.9 accounts for a 10% dissipation of food energy consumed by the thermic effect of food) and related to predicted basal energy expenditures for 30-year-old men calculated from the predictive basal energy expenditure equations in Chapter 5; see "Estimation of Energy Expenditure in Normal and Overweight/Obese Adults."

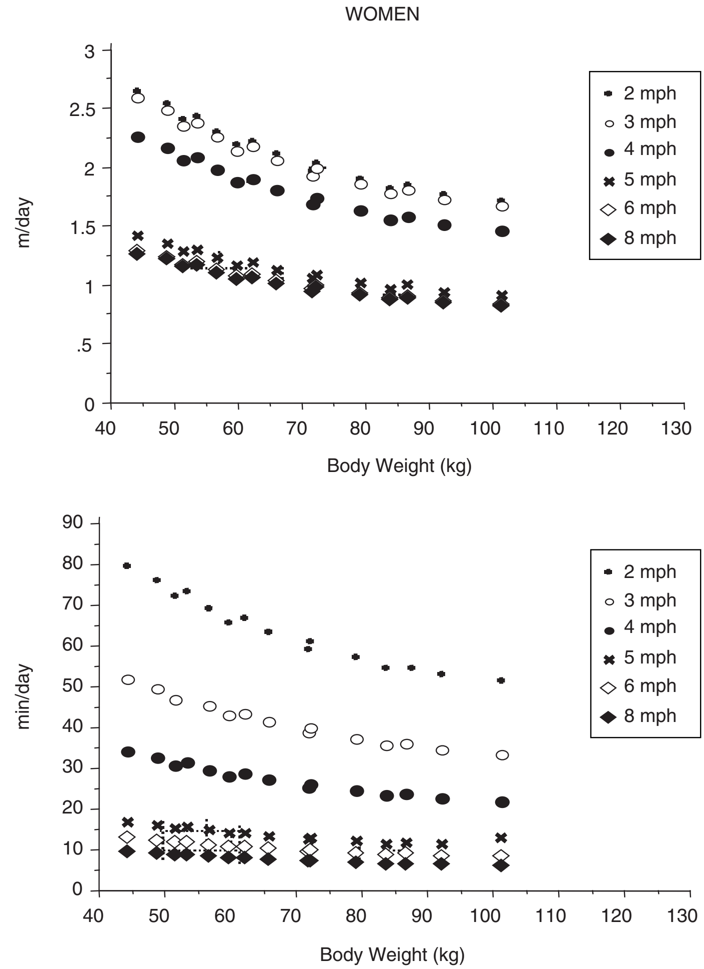

FIGURE 12-6 Distance to cover per day for women to raise physical activity level (PAL) value by 0.10 while walking or running at various speeds (upper panel) and time required to do so (lower panel). The points shown are for women with reference heights of 1.62 m or reference heights ± 1 standard deviation (i.e., 1.55 m or 1.70 m) and a body mass index of 18.5, 22.5, 25, 30, or 35 kg/m^2. Energy expenditures while walking or running at speeds of 2, 3, 4, 5, or 8 mph are 2.5, 3.3, 4.5, 8.0, 10.2, and 13.5 metabolic equivalents (METs), respectively (Fletcher et al., 2001). The impact on ΔPAL was calculated as (MET – 1.0) × minutes × 1.15 ÷ 0.9 (where 1.15 accounts for excess [~15%] post-exercise oxygen consumption [Bahr et al., 1987] and 0.9 accounts for a 10 percent dissipation of food energy consumed by the thermic effect of food) and related to predicted basal energy expenditures for 30-year-old women calculated from the predictive basal energy expenditure (BEE) equations in Chapter 5; see "Estimation of Energy Expenditure in Normal and Overweight/Obese Adults."

intensity activities must be included to achieve high PAL levels if the time spent exercising is to remain within a certain range. Cross-sectional data from a doubly labeled water database indicate that the PALs are similar for normal weight and obese individuals (Tables 5-10 and 5-11). While this is true, because energy expenditure increases with increasing body weight, there is a greater total daily energy expenditure in obese subjects (Table 5-10 and 5-11).

Physical Activity for Adults

The rationale for categorizing the cross-sectional data on adults in the doubly labeled water (DLW) database by PAL (Appendix Table I-3), as sedentary ($PAL \geq 1.0 < 1.4$), low active ($PAL \geq 1.4 < 1.6$), active ($PAL \geq 1.6 < 1.9$), and very active ($PAL \geq 1.9 < 2.5$) categories is provided in Chapter 5. Ideally, PAL of an individual can be determined from DLW studies; however, in nonexperimental situations, heart rate monitors, accelerometers, and other devices as well as activity inventories can be used. As explained earlier, the PAL coefficients in Tables 12-1 to 12-3 are based on rates of energy expenditure during physical activity reported in terms of METs, with an allowance for the EPOC induced by physical activities and the TEF that needs to be consumed to cover the overall cost of these activities.

Table 12-2 shows how adults can use the information presented in Table 12-1 to evaluate their PAL based on their daily activities. In the example shown in Table 12-2, the "sedentary" column illustrates the impact of an adult's typical daily living activities on the PAL ratio of TEE:BEE. This activity-induced increase in PAL of 0.29 is to be added to a base value of 1.1, which represents the BEE of 1.0 to which 10 percent has been added to account for the dissipation of energy due to the TEF that needs to be consumed to cover BEE. This adds up to a sedentary PAL value of 1.39, which corresponds to a sedentary lifestyle ($PAL \geq 1.0 < 1.4$). Incorporating a 30 min/day walk at a speed of 4 mph raises the PAL to 1.49 ("low active" column), which corresponds to a low active lifestyle ($PAL \geq 1.4 < 1.6$). If in addition to walking 30 min/day at a speed of 4 mph, an adult cycled moderately for another 25 minutes and played tennis for 40 minutes, the PAL would increase to 1.75 (the first "active" column), which reflects an active lifestyle ($PAL \geq 1.6 < 1.9$). The second "active" column illustrates a mix of activities as reflected by the average time spent per day on various forms of activity and exercise. Finally, the "very active" column describes a level of activity corresponding to a PAL of 2.06, indicative of a very active lifestyle ($PAL \geq 1.9 < 2.5$).

Because activities vary greatly from day to day, a person's PAL can be more accurately evaluated from a meticulous activity log maintained over a period of a week or more. The example in Table 12-3 describes an adult

TABLE 12-2 Intensity and Impact of Various Activities on Physical Activity Level (PAL) Estimations (Daily Example)

Activity	METs[a]	ΔPAL/ 10 min	ΔPAL/h
Leisure			
Mild			
Billiards	2.4	0.013	0.08
Canoeing (leisurely)	2.5	0.014	0.09
Dancing (ballroom)	2.9	0.018	0.11
Golf (with cart)	2.5	0.014	0.09
Horseback riding (walking)	2.3	0.012	0.07
Playing			
Accordion	1.8	0.008	0.05
Cello	2.3	0.012	0.07
Flute	2.0	0.01	0.06
Piano	2.3	0.012	0.07
Violin	2.5	0.014	0.09
Volleyball (noncompetitive)	2.9	0.018	0.11
Walking (2 mph)	2.5	0.014	0.09
Moderate			
Calisthenics (no weight)	4.0	0.029	0.17
Cycling (leisurely)	3.5	0.024	0.14
Golf (without cart)	4.4	0.032	0.19
Swimming (slow)	4.5	0.033	0.20
Walking (3 mph)	3.3	0.022	0.13
Walking (4 mph)	4.5	0.033	0.20
Vigorous			
Chopping wood	4.9	0.037	0.22
Climbing hills (no load)	6.9	0.056	0.34
Climbing hills (5-kg load)	7.4	0.061	0.37
Cycling (moderately)	5.7	0.045	0.27
Dancing			
Aerobic or ballet	6.0	0.048	0.29
Ballroom (fast) or square	5.5	0.043	0.26
Jogging (10-min miles)	10.2	0.088	0.53
Rope skipping	12.0	0.105	0.63
Skating			
Ice	5.5	0.043	0.26
Roller	6.5	0.052	0.31
Skiing (water or downhill)	6.8	0.055	0.33
Squash	12.1	0.106	0.63
Surfing	6.0	0.048	0.29
Swimming	7.0	0.057	0.34
Tennis (doubles)	5.0	0.038	0.23
Walking (5 mph)	8.0	0.067	0.40

Sedentary[b]		Low Active[b]		Active[b]		Active (Mix)[b]		Very Active[b]	
Min	ΔPAL	Min	ΔPAL	Min	ΔPAL	Avg Min	ΔPAL	Min	ΔPAL
						10	0.014		
						10	0.012		
						10	0.012		
						10	0.029		
						10	0.032		
						10	0.022		
		30	0.099	30	0.099	10	0.033		
				25	0.113			45	0.203
						10	0.088	15	0.132
								10	0.105
						10	0.057		
				40	0.152	20	0.076	60	0.228

continued

TABLE 12-2 Continued

Activity	METs[a]	ΔPAL/ 10 min	ΔPAL/h
Activities of daily living			
Gardening (no lifting)	4.4	0.032	0.19
Household tasks, moderate effort	3.5	0.024	0.14
Lifting items continuously	4.0	0.029	0.17
Light activity while sitting	1.5	0.005	0.03
Loading/unloading car	3.0	0.019	0.11
Lying quietly	1.0	0	0
Mopping	3.5	0.024	0.14
Mowing lawn (power mower)	4.5	0.033	0.20
Raking lawn	4.0	0.029	0.17
Riding in a vehicle	1.0	0	0
Taking out trash	3.0	0.019	0.11
Vacuuming	3.5	0.024	0.14
Walking the dog	3.0	0.019	0.11
Walking from house to car or bus	2.5	0.014	0.09
Watering plants	2.5	0.014	0.09
ΔPAL/day due to activities of daily living			
Sedentary PAL = basal energy expenditure (BEE) + thermic effect of food (0.1 × BEE) + sedentary activities =			
ΔPAL due to exercise and leisure activities		ΔPAL /day	
		PAL =	

[a] METs are multiples of an individual's resting oxygen (O_2) uptake, defined as a rate of O_2 consumption of 3.5 mL of O_2/min/kg body weight in adults.

whose activities of daily living raises energy expenditure to a sedentary PAL of 1.39 (PAL ≥ 1.0 < 1.4). If the individual recorded all additional activities over the week and added all of the ΔPALs for each of the activities performed as shown in Table 12-3, the adult would have had a mean increase in PAL of 0.65/day above basal expenditure. Thus, when added to the PAL of 1.1 (representing a base BEE value of 1.0 + 10 percent for TEF), this individual would move into the "active" category with a PAL of 1.75 (PAL ≥ 1.6 < 1.9).

A somewhat simplified approach, instead of recording all activities, would be to evaluate whether the level of daily living activities is comparable to that depicted in Tables 12-2 and 12-3. If they are, then a log of daily activities may be kept, and their average ΔPAL could be added to the PAL value (1.39) corresponding to that for a sedentary lifestyle in the example in Tables 12-2 and 12-3.

Sedentary[b]		Low Active[b]		Active[b]		Active (Mix)[b]		Very Active[b]	
Min	ΔPAL	Min	ΔPAL	Min	ΔPAL	Avg Min	ΔPAL	Min	ΔPAL
25	0.060	25	0.060	25	0.060	25	0.060	25	0.060
120	0.060	120	0.060	120	0.060	120	0.060	120	0.060
5	0.010	5	0.010	5	0.010	5	0.010	5	0.010
10	0.024	10	0.024	10	0.024	10	0.024	10	0.024
10	0.029	10	0.029	10	0.029	10	0.029	10	0.029
5	0.010	5	0.010	5	0.010	5	0.010	5	0.010
10	0.024	10	0.024	10	0.024	10	0.024	10	0.024
15	0.029	15	0.029	15	0.029	15	0.029	15	0.029
20	0.028	20	0.028	20	0.028	20	0.028	20	0.028
12	0.017	12	0.017	12	0.017	12	0.017	12	0.017
	0.29		0.29		0.29		0.29		0.29
	1.39		1.39		1.39		1.39		1.39
			0.10		0.36		0.38		0.67
	1.39		**1.49**		**1.75**		**1.77**		**2.06**

[b] PAL levels are Sedentary: PAL ≥ 1.0 < 1.4; Low Active: PAL ≥ 1.4 < 1.6; Active: PAL ≥ 1.6 < 1.9; Active (Mix): PAL ≥ 1.6 < 1.9; Very Active: PAL ≥ 1.9 < 2.5.

The factorial approach summations of various estimates of activities and durations applied in Tables 12-2 and 12-3 to evaluate energy turnover is more convenient than previous procedures inasmuch as it is applicable without making reference to body weight, as required, though often ignored, in estimating increments in energy expenditure in terms of their cost in kcal. Furthermore, the ΔPAL coefficients in Table 12-1 include an appropriate allowance for EPOC and TEF, whose effects are commonly disregarded when evaluating energy turnover. However, it must be remembered that the reliability of evaluations of overall energy expenditure and ΔPALs depends greatly on the accuracy of the activity estimates or activity logs and on whether they were obtained during a period representative of the habitual lifestyle. Because intentional and spontaneous activities are interrelated, assessing ΔPALs of individuals and populations can be more difficult. From the standpoint of energetics, any activity raises metabolic

TABLE 12-3 Weekly Activities and Their Impact on Physical Activity Level (PAL) in an Active Individual (Weekly Activity Log)

Activity	METs[a]	ΔPAL/ 10 min	ΔPAL/h
Leisure			
Mild			
Billiards	2.4	0.013	0.08
Canoeing (leisurely)	2.5	0.014	0.09
Dancing (ballroom)	2.9	0.018	0.11
Golf (with cart)	2.5	0.014	0.09
Horseback riding (walking)	2.3	0.012	0.07
Playing			
Accordion	1.8	0.008	0.05
Cello	2.3	0.012	0.07
Flute	2.0	0.010	0.06
Piano	2.3	0.012	0.07
Violin	2.5	0.014	0.09
Volleyball (noncompetitive)	2.9	0.018	0.11
Walking (2 mph)	2.5	0.014	0.09
Moderate			
Calisthenics (no weight)	4.0	0.029	0.17
Cycling (leisurely)	3.5	0.024	0.14
Golf (without cart)	4.4	0.032	0.19
Swimming (slow)	4.5	0.033	0.2
Walking (3 mph)	3.3	0.022	0.13
Walking (4 mph)	4.5	0.033	0.2
Vigorous			
Chopping wood	4.9	0.037	0.22
Climbing hills (no load)	6.9	0.056	0.34
Climbing hills (5-kg load)	7.4	0.061	0.37
Cycling (moderately)	5.7	0.045	0.27
Dancing			
Aerobic or ballet	6.0	0.048	0.29
Ballroom (fast) or square	5.5	0.043	0.26
Jogging (10-min miles)	10.2	0.088	0.53
Rope skipping	12.0	0.105	0.63
Skating			
Ice	5.5	0.043	0.26
Roller	6.5	0.052	0.31
Skiing (water or downhill)	6.8	0.055	0.33
Squash	12.1	0.106	0.63
Surfing	6.0	0.048	0.29
Swimming	7.0	0.057	0.34
Tennis (doubles)	5.0	0.038	0.23
Walking (5 mph)	8.0	0.670	0.40

Weekly Activity Log								
Day 1 (min)	Day 2 (min)	Day 3 (min)	Day 4 (min)	Day 5 (min)	Day 6 (min)	Day 7 (min)	Total Minutes	ΔPAL
				20			20	0.036
	30					60	90	0.105
15					10		25	0.030
				50			50	0.092
					80		80	0.253
60							60	0.130
		50					50	0.167
						100	100	0.617
			40				40	0.180
		20		10			30	0.265
		30					30	0.170
	60				60		120	0.460

continued

TABLE 12-3 Continued

Activity	METs[a]	ΔPAL/ 10 min	ΔPAL/h
Activities of daily living			
Gardening (no lifting)	4.4	0.032	0.19
Household tasks, moderate effort	3.5	0.024	0.14
Lifting items continuously	4.0	0.029	0.17
Light activity while sitting	1.5	0.005	0.03
Loading/unloading car	3.0	0.019	0.11
Lying quietly	1.0	0	0
Mopping	3.5	0.024	0.14
Mowing lawn (power mower)	4.5	0.033	0.2
Raking lawn	4.0	0.029	0.17
Riding in a vehicle	1.0	0	0
Taking out trash	3.0	0.019	0.11
Vacuuming	3.5	0.024	0.14
Walking the dog	3.0	0.019	0.11
Walking from house to car or bus	2.5	0.014	0.09
Watering plants	2.5	0.014	0.09
Min spent on daily living activities			
Min spent on daily leisure activities and exercise			

[a] METs are multiples of an individual's resting oxygen (O_2) uptake, defined as a rate of O_2 consumption of 3.5 mL of O_2/min/kg body weight in adults.

rate over basal and thus helps in raising energy expenditure. Some activities, such as fidgeting, are spontaneous and can have variable effects on TEE (see Chapter 5 "Spontaneous Non-Exercise Activity"). In room calorimeters, the metabolic costs of unintentional, nondirected activities can be quantified (Ravussin et al., 1986).

Physical Activity for Children

Measurements of the energy expended in various activities are much more limited in children than adults. Torun (1990) compiled the energy expenditure of several common activities in children from 28 studies and expressed the data as multiples of basal metabolic rate (BMR). The activities

Weekly Activity Log								
Day 1 (min)	Day 2 (min)	Day 3 (min)	Day 4 (min)	Day 5 (min)	Day 6 (min)	Day 7 (min)	Total Minutes	ΔPAL
10	30	20	40	10	20	20	150	0.350
160	160	180	160	160	90	90	1,000	0.500
				10	10	20	40	0.073
	20			10		10	40	0.093
			50				50	0.165
20					20		40	0.113
					20		20	0.038
30				30			60	0.140
	30			45		30	105	0.193
30	30	30	30	30	20	20	190	0.285
			30			20	50	0.075
250	270	230	310	295	180	210	1,745	2.025
75	90	100	40	80	150	160	695	2.505

ΔPAL/week = 2.025 + 2.505 = 4.530
mean ΔPAL/day = 4.53/7 = 0.65
mean PAL = 1.1 + mean ΔPAL/day = 1.75

were classified into 10 categories as shown in Tables 12-4 (Boys) and 12-5 (Girls). When the data are expressed as multiples of BMR, the values are similar for boys and girls. There are no age-related differences for sedentary activities (lying awake, sitting), but the values for walking and moving around increases from early childhood to adolescence. Kimm and colleagues (2002) reported a decline in physical activity in girls during adolescence. The impact of performing various activities for 10 and 60 minutes on PAL also are shown for children in Tables 12-4 and 12-5. The use of MET values for various activities measured in adults leads to errors that increase with decreasing age in children.

To classify children into PAL categories, judgment must be made on their PAL. In Tables 12-6 and 12-7, the differences in energy expenditure

TABLE 12-4 Various Activities: Intensity and Impacts on Physical Activity Level (PAL) in Children (Boys)

	Energy Expenditure (kcal/kg/min)					Energy expenditure of categories of activity at different ages expressed as multiples of BMR (Torun, 1990)				
Age (y)	1.5–6	7–12	13–14	15–16	17–19	1.5–6	7–12	13–14	15–16	17–19
Activity										
Lying awake	0.046	0.035	0.026	0.024	0.020	1.1	1.1	1.0	1.1	1.1
Sitting quietly	0.047	0.037	0.028	0.028	0.026	1.2	1.2	1.1	1.2	1.4
Standing quietly			0.029	0.033	0.027			1.3	1.5	1.5
Standing, moderate movement		0.069	0.052	0.052			2.2	2.1	2.4	
Walking, free velocity, level ground	0.078	0.078	0.066	0.066	0.053	2.1	2.9	2.8	3.3	3.1
Walking, fast, uphill or with load	0.098	0.110	0.103	0.094		2.6	3.4	3.8	4.4	
At school or light work		0.055–0.084			0.030		1.9–3.0			1.7
Light and moderate housework										
Leisure and moderate play	0.073–0.094	0.061–0.126	0.056–0.075	0.054		1.9–2.5	2.3–4.7	2.5–3.3	2.5	
Running, exercise sports			0.068–0.132	0.067	0.072–0.099			3.1–5.6	3.6	3.9–5.4

TABLE 12-5 Various Activities: Intensity and Impacts on Physical Activity Level (PAL) in Children (Girls)

	Energy Expenditure (kcal/kg/min)					Energy expenditure of categories of activity at different ages expressed as multiples of BMR (Torun, 1990)				
Age (y)	1.5–6	7–12	13–14	15–16	17–19	1.5–6	7–12	13–14	15–16	17–19
Activity										
Lying awake	0.046			0.018	0.018	1.1			1.1	1.1
Sitting quietly	0.047	0.032	0.027	0.021	0.021	1.2	1.2	1.4	1.2	1.2
Standing quietly			0.028	0.024	0.024			1.4	1.4	1.4
Standing, moderate movement										
Walking, free velocity, level ground	0.078	0.068	0.059	0.057	0.057	2.1	2.7	3.2	3.4	3.4
Walking, fast, uphill or with load	0.098					2.6				
At school or light work				0.026–0.031	0.026–0.031				1.6–1.8	1.6–1.8
Light and moderate housework				0.046–0.058	0.046–0.058				2.9–3.6	2.9–3.6
Leisure and moderate play	0.073–0.094			0.032–0.050	0.032–0.050	1.9–2.5			1.9–3.1	1.9–3.1
Running, exercise sports				0.067–0.100	0.067–0.100				3.9–5.9	3.9–5.9

	ΔPAL/10 min					ΔPAL/60 min				
	1.5–6	7–12	13–14	15–16	17–19	1.5–6	7–12	13–14	15–16	17–19
	0.0009	0.0009	0.0000	0.0009	0.0009	0.0053	0.0053	0.0000	0.0053	0.0053
	0.0018	0.0018	0.0009	0.0018	0.0036	0.0107	0.0107	0.0053	0.0107	0.0213
			0.0027	0.0044	0.0044			0.0160	0.0266	0.0266
		0.0107	0.0098	0.0124			0.0639	0.0586	0.0746	
	0.0098	0.0169	0.0160	0.0204	0.0186	0.0586	0.1012	0.0959	0.1225	0.1118
	0.0142	0.0213	0.0249	0.0302		0.0852	0.1278	0.1491	0.1811	
		0.008–0.018			0.0062		0.048–0.108			0.0373
	0.008–0.013	0.012–0.033	0.013–0.020	0.0133		0.048–0.078	0.072–0.198	0.078–0.120	0.0799	
			0.019–0.041	0.0231	0.026–0.039			0.114–0.246	0.1385	

	ΔPAL/10 min					ΔPAL/60 min				
	1.5–6	7–12	13–14	15–16	17–19	1.5–6	7–12	13–14	15–16	17–19
	0.0009			0.0009	0.0009	0.0053			0.0053	0.0053
	0.0018	0.0018	0.0036	0.0018	0.0018	0.0107	0.0107	0.0213	0.0107	0.0107
			0.0036	0.0036	0.0036			0.0213	0.0213	0.0213
	0.0098	0.0151	0.0195	0.0213	0.0213	0.0586	0.0905	0.1172	0.1278	0.1278
	0.0142					0.0852				
				0.005–0.007	0.005–0.007				0.030–0.042	0.030–0.042
				0.017–0.023	0.017–0.023				0.102–0.138	0.102–0.138
	0.008–0.013			0.008–0.019	0.008–0.019	0.048–0.078			0.048–0.114	0.048–0.114
				0.026–0.043	0.026–0.043				0.156-0.258	0.156-0.258

TABLE 12-6 Total Energy Expenditure (TEE) in Boys and Walking Times at Speeds of 2.5 mph to Move to the Next Higher Physical Activity Level (PAL)

						TEE (kcal/d)				PAL
Age (y)	Weight (kg)[a]	Height (m)[a]	BEE (kcal/d)[b]	BEE METs (kcal/kg/min)[c]	BEE METs (kcal/kg/hr)	Sedentary PAL[d]	Low Active PAL[d]	Active PAL[d]	Very Active PAL[d]	Low Active PAL[e]
3	14.3	0.95	889	0.043	2.59	1,142	1,304	1,465	1,663	1.47
4	16.2	1.02	935	0.040	2.40	1,195	1,370	1,546	1,763	1.47
5	18.4	1.09	985	0.037	2.23	1,255	1,446	1,638	1,874	1.47
6	20.7	1.15	1,030	0.035	2.07	1,308	1,515	1,722	1,977	1.47
7	23.1	1.22	1,084	0.033	1.95	1,373	1,597	1,820	2,095	1.47
8	25.6	1.28	1,132	0.031	1.84	1,433	1,672	1,911	2,205	1.48
9	28.6	1.34	1,187	0.029	1.73	1,505	1,762	2,018	2,334	1.48
10	31.9	1.39	1,240	0.027	1.62	1,576	1,850	2,124	2,461	1.49
11	35.9	1.44	1,303	0.025	1.51	1,666	1,960	2,254	2,615	1.50
12	40.5	1.49	1,376	0.024	1.42	1,773	2,088	2,403	2,792	1.52
13	45.6	1.56	1,471	0.022	1.34	1,910	2,251	2,593	3,013	1.53
14	51.0	1.64	1,578	0.021	1.29	2,065	2,434	2,804	3,258	1.54
15	56.3	1.70	1,669	0.021	1.23	2,198	2,593	2,988	3,474	1.55
16	60.9	1.74	1,734	0.020	1.19	2,295	2,711	3,127	3,638	1.56
17	64.6	1.75	1,764	0.019	1.14	2,341	2,771	3,201	3,729	1.57
18	67.2	1.76	1,777	0.018	1.10	2,358	2,798	3,238	3,779	1.57

[a] From Chapter 5, Table 5-8.
[b] BEE = Basal Energy Expenditure, calculated from equations in Chapter 5; see "TEE Equations for Normal-Weight Children."
[c] MET = Metabolic Equivalents as calculated from BEE/weight (kg)/1,440 minutes (1 day).
[d] From Chapter 5, Table 5-20.
[e] PAL = Physical Activity Level = TEE/BEE.

above the sedentary level for the low active, active, and very active PAL categories have been expressed in terms of minutes walking at 2.5 mph. Because the BEE and walking energy expenditure (kcal/kg/min) decrease with age differentially, the MET equivalent for walking is not constant and actually increases with age (see Tables 12-6 and 12-7). Thus, the energy cost of walking 2.5 mph decreases from 0.92–0.75 to 0.04–0.05 kcal/kg/min from early childhood to adolescence, and the corresponding MET values increase from ~2.0 to ~3.0.

Examining the number of minutes of walking that would be required to go from the sedentary to the low active (~120 minutes), active (~230 minutes), and very active (~400 minutes) categories, it is clear that children in the active and very active categories are most likely participating in moderate and vigorous activities, in addition to walking at 2.5 mph. With

Active PAL[e]	Very Active PAL[e]	Difference in energy expenditure from sedentary level (kcal/d): Low Active–Sedentary	Active–Sedentary	Very Active–Sedentary	Energy cost of walking 2.5 mph (kcal/kg/2.5 min)[f]	METs of walking mph[g]	Walking equivalent (min)[h]: Low Active–Sedentary	Active–Sedentary	Very Active–Sedentary
1.65	1.87	162	323	521	0.092	2.13	123	246	396
1.65	1.89	175	351	568	0.089	2.23	121	242	392
1.66	1.90	191	383	619	0.087	2.34	119	239	387
1.67	1.92	207	414	669	0.084	2.44	118	237	383
1.68	1.93	224	447	722	0.082	2.52	118	236	381
1.69	1.95	239	478	772	0.079	2.59	118	235	380
1.70	1.97	257	513	829	0.077	2.67	117	233	377
1.71	1.98	274	548	885	0.074	2.76	115	231	373
1.73	2.01	294	588	949	0.072	2.85	114	228	367
1.75	2.03	315	630	1,019	0.069	2.94	112	224	362
1.76	2.05	341	683	1,103	0.067	2.99	112	224	361
1.78	2.06	369	739	1,193	0.064	3.00	112	225	363
1.79	2.08	395	790	1,276	0.062	3.01	113	227	366
1.80	2.10	416	832	1,343	0.059	3.01	115	230	371
1.81	2.11	430	860	1,388	0.057	3.00	117	234	377
1.82	2.13	440	880	1,421	0.054	2.96	120	241	388

[f] Determined from treadmill testing (Puyau et al., 2002; Treuth et al., 1998; Treuth et al., 2000; Treuth et al. (2003).
[g] Calculated as energy cost of walking 2.5 mph (kcal/kg/min) divided by BEE MET (kcal/kg/min).
[h] Calculated by dividing the difference in energy expenditure from sedentary level (kcal/d) by the energy cost of walking 2.5 mph (kcal/kg/min) × weight (kg).

information on the number of minutes children spend in moderate and vigorous play and work, the appropriate PAL category can be assigned.

Physical Activity for Pregnant Women

For women who have been previously physically active, continuation of physical activities during pregnancy and postpartum can be advantageous (Mottola and Wolfe, 2000). Unfortunately, too much or improper activity can be injurious to the woman and fetus. Regular exercise during pregnancy counteracts the effects of deconditioning that lead to fatigue, loss of muscle tone, poor posture, joint laxity, back pain, and muscle cramping (Brooks et al., 2000). Likewise, physical fitness improves glucose tolerance and insulin action, improves emotional well-being and helps

TABLE 12.7 Total Energy Expenditure (TEE) in Girls and Walking Times at Speeds of 2.5 mph to Move to the Next Higher Physical Activity Level (PAL)

						TEE (kcal/d)				PAL
Age (y)	Weight (kg)[a]	Height (m)[a]	BEE (kcal/d)[b]	BEE METs (kcal/kg/min)[c]	BEE METs (kcal/kg/hr)	Sedentary PAL[d]	Low Active PAL[d]	Active PAL[d]	Very Active PAL[d]	Low Active PAL[e]
3	13.9	0.94	879	0.044	2.63	1,060	1,223	1,375	1,629	1.39
4	15.8	1.01	910	0.040	2.40	1,113	1,290	1,455	1,730	1.42
5	17.9	1.08	943	0.037	2.20	1,169	1,359	1,537	1,834	1.44
6	20.2	1.15	979	0.034	2.02	1,227	1,431	1,622	1,941	1.46
7	22.8	1.21	1,014	0.031	1.85	1,278	1,495	1,699	2,038	1.47
8	25.6	1.28	1,056	0.029	1.72	1,340	1,573	1,790	2,153	1.49
9	29.0	1.33	1,094	0.026	1.57	1,390	1,635	1,865	2,248	1.49
10	32.9	1.38	1,139	0.024	1.44	1,445	1,704	1,947	2,351	1.50
11	37.2	1.44	1,193	0.022	1.34	1,513	1,788	2,046	2,475	1.50
12	41.6	1.51	1,253	0.021	1.26	1,592	1,884	2,158	2,615	1.50
13	45.8	1.57	1,306	0.020	1.19	1,659	1,967	2,256	2,737	1.51
14	49.4	1.60	1,337	0.019	1.13	1,693	2,011	2,309	2,806	1.50
15	52.0	1.62	1,351	0.018	1.08	1,706	2,032	2,337	2,845	1.50
16	53.9	1.63	1,352	0.017	1.05	1,704	2,034	2,343	2,858	1.50
17	55.1	1.63	1,340	0.017	1.01	1,685	2,017	2,328	2,846	1.51
18	56.2	1.63	1,327	0.016	0.98	1,665	1,999	2,311	2,833	1.51

[a] From Chapter 5, Table 5-9.
[b] BEE = Basal Energy Expenditure, calculated from equations in Chapter 5; see "TEE Equations for Normal-Weight Children."
[c] MET = Metabolic Equivalents as calculated from BEE/weight (kg)/1,440 minutes (1 day).
[d] From Chapter 5, Table 5-21.
[e] PAL = Physical Activity Level = TEE/BEE.

prevent excessive weight gain. Fitness promotes faster delivery, which is considered beneficial to mother and baby, and hastens recovery from pregnancy. Moreover, resumption of physical activity after pregnancy is important for restoration of normal body weight. Women who gain more than the recommended weight during pregnancy and who fail to lose this weight 6 months after giving birth are at much higher risk of being obese nearly a decade later (Rooney and Schauberger, 2002). Professional organizations such as the American College of Obstetricians and Gynecologists (ACOG) have published guidelines and specific recommendations for exercise by women before, during, and after pregnancy (ACOG, 1994).

A full description of the benefits and hazards of exercise for the pregnant woman and fetus is beyond the scope of this report. Physically active

		Difference in energy expenditure from sedentary level (kcal/d)			Energy cost of walking		Walking equivalent (min)[h]		
Active PAL[e]	Very Active PAL[e]	Low Active–Sedentary	Active–Sedentary	Very Active–Sedentary	2.5 mph (kcal/kg/2.5 min)[f]	METs of walking mph[g]	Low Active–Sedentary	Active–Sedentary	Very Active–Sedentary
1.57	1.85	163	315	569	0.095	2.16	124	239	432
1.60	1.90	177	342	617	0.091	2.28	123	237	428
1.63	1.94	190	368	665	0.088	2.40	121	234	423
1.66	1.98	204	395	714	0.085	2.51	119	231	418
1.68	2.01	217	421	760	0.081	2.63	117	228	411
1.70	2.04	233	450	813	0.078	2.72	117	226	408
1.70	2.05	245	475	858	0.074	2.84	114	220	398
1.71	2.06	259	502	906	0.071	2.96	111	215	388
1.72	2.07	275	533	962	0.068	3.04	109	212	382
1.72	2.09	292	566	1,023	0.064	3.07	109	212	383
1.73	2.10	308	597	1,078	0.061	3.07	110	214	387
1.73	2.10	318	616	1,113	0.058	3.06	112	217	392
1.73	2.11	326	631	1,139	0.054	3.00	116	224	405
1.73	2.11	330	639	1,154	0.051	2.91	121	234	422
1.74	2.12	332	643	1,161	0.047	2.81	127	246	445
1.74	2.13	334	646	1,168	0.044	2.68	135	261	472

[f] Determined from treadmill testing (Puyau et al., 2002; Treuth et al., 1998; Treuth et al., 2000; Treuth et al. (2003).
[g] Calculated as energy cost of walking 2.5 mph (kcal/kg/min) divided by BEE MET (kcal/kg/min).
[h] Calculated by dividing the difference in energy expenditure from sedentary level (kcal/d) by the energy cost of walking 2.5 mph (kcal/kg/min) × weight (kg).

TABLE 12-8 Target Heart Rate Zones for Healthy Pregnant Women

Age (y)	Heart Rate (beats/min)
< 20	140–155
20–29	135–150
30–39	130–145
> 40	125–140

SOURCE: Mottola and Wolfe, 2000.

and fit women should consult with their physician on how to exercise safely during pregnancy, and probably no pregnant woman should begin an exercise-training program without medical evaluation and exercise instruction. To an extent, anatomy and physiology protect the fetus from injury because the uterus provides a protective environment, the placenta can use alternative energy fuels (e.g., lactate), and fetal blood has a higher affinity of oxygen than does adult hemoglobin (Mottola and Wolfe, 2000). However, excessive exercise or incorrect exercise could compromise placental blood flow, expose the fetus to hypoxemia (low blood oxygen), hypoglycemia (low blood sugar), or hyperthermia (high body temperature), or increase risk of trauma to woman and fetus. Excessive exercise could increase the risk of preterm delivery and lower birth weight (ACOG, 1994).

Education, common sense, and the feeling of body wellness that comes from regular physical activity can be important in guiding a pregnant woman who wants to retain the health benefits of physical activity. For instance, moderate-intensity, rhythmical activities (walking, cycling, swimming, jogging, and dancing) are recommended, whereas activities such as water skiing, surfing, scuba diving, and mountaineering at high altitudes pose unknown risks to the fetus and are not recommended at any time during pregnancy (ACOG, 1995). Similarly, intense physical activity and exercising for extended periods while dehydrated, under hot environmental conditions, and while fasted may increase the risk of hyperthermia and hypoglycemia. Usually, as pregnancy progresses, women instinctively alter exercise activity patterns. Women also need be aware to change or enhance exercise equipment, such as switching from supine to upright cycling. ACOG publishes several texts (e.g., *Encyclopedia of Women's Health*) and brochures (e.g., "Wellness Exercise During Pregnancy") that provide advice for the general public and health professionals.

Historically, concern has been that intense physical activity could result in low birth weight infants and preterm delivery, but this concern needs to be balanced against the need to control body weight during pregnancy and afterward and current evidence that prudent physical activity performed at moderate intensities within current guidelines has no adverse effects on fetal development (Mottola and Wolfe, 2000). Exercise prescriptions for pregnant women are not dissimilar to those for other adults. Exercise sessions should be preceded by a 5- to 15-minute warm-up, and followed by a similar cool-down period. Training duration should be 15 to 30 minutes. Exercise frequency should be 3 to 5 times per week, and not increase in frequency during first or third trimesters because of fatigue and an evaluation of risks to benefits. Exercise intensity should be moderate and elicit 60 to 70 percent Vo_2max, which can be monitored by the maternal heart rate response as shown in Table 12-8. Alternatively, on the 20-point

Borg Rating of Perceived Exertion Scale, women should be exercising at an intensity between 12 and 14 ("somewhat hard"). And finally, intensity can be gauged by the talk test, or exercise intensity where lactic acidosis drives pulmonary minute ventilation so that the pregnant woman is out of breath and cannot carry on a conversation.

Physical Activity Level Consistent with a Normal Body Mass Index

Based on Table 12-2, 30 minutes of moderately intensive physical activity (ΔPAL = 0.099 for walking at 4 mph) would be sufficient to raise the PAL of a person doing only the activities of daily living (PAL = 1.39) from the "sedentary" category (PAL $\geq$ 1.0 < 1.4), to the "low active" category (PAL $\geq$ 1.4 < 1.6), but insufficient to raise the PAL to the "active" category (PAL $\geq$ 1.6 < 1.9), the average PAL category of normal weight adults in the DLW database with BMIs from 18.5 up to 25 kg/m^2 (Table 5-10). One hour of moderately intensive physical activity (ΔPAL = 0.2 for walking at 4 mph) would raise the PAL from 1.39 to 1.59, the upper range of the low active category (PAL $\geq$ 1.4 < 1.6). Thus on the average, an energy expenditure equivalent to at least 60 minutes of moderate intensity physical activity is required to raise the PAL from the "sedentary" to the "active" category (PAL $\geq$ 1.6 < 1.9).

Physical Activity Recommendations for Adults and Children

Cross-sectional data from the DLW database were used to define a recommended level of physical activity for adults and children, based on the PAL associated with a normal BMI range of 18.5 to 25 kg/m^2 (Chapter 5). Factors known to affect body weight were controlled for in the DLW studies, allowing for a reliable assessment of the level of physical activity consistent with a normal weight. Because an average of 60 min/day of moderate intensity physical activity provides a PAL that is associated with a normal BMI range, this is the amount of activity that is recommended for normal weight adults. As stated in Chapter 4, the Dietary Reference Intakes are provided for the apparently healthy population, therefore recommended levels of physical activity that would result in weight loss of overweight or obese individuals are not provided.

In terms of making a realistic physical activity recommendation for busy individuals to maintain their weight, it is important to recognize that exercise and activity recommendations consider "accumulated" physical activity. This involves consideration of EEPAs of both low intensity activities of daily life (e.g., taking the stairs at work) as well as participating in more vigorous activities (e.g., taking an aerobics class). Recognition of the value of accumulated physical activity in raising TEE makes reasonable activity patterns and sedentary occupations compatible by including significant amounts of moderate intensity activity (e.g., 60 minutes/day of brisk walking) or exercises requiring high intensities (e.g., jogging or running) performed regularly (4–7 days/week).

It is difficult to determine a quantifiable recommendation for physical activity based on reduced risk of chronic disease. Meeting the 60 minute/day physical activity recommendation, however, offers additional benefits in reducing risk of chronic diseases, for example, by favorably altering blood lipid profiles, changing body composition by decreasing body fat and increasing muscle mass, or both (Eliakim et al., 1997; Schwartz et al., 1991; Wei et al., 1997; Wilbur et al., 1999).

EVIDENCE FOR HEALTHFUL EFFECTS OF PHYSICAL ACTIVITY

Epidemiological Evidence for Reduced Risk of Chronic Diseases and Mortality

Men and women with moderate to high levels of physical activity or cardio-respiratory fitness have lower mortality rates than sedentary individuals with low fitness (Blair et al., 1993; Colditz and Coakley, 1997; Myers et al., 2002; Paffenbarger et al., 1994; Sandvik et al., 1993). For instance, in a study of Harvard alumni, mortality rates for men walking on average less than 9 miles each week were 15 percent higher than in men walking more than 9 miles a week (Paffenbarger et al., 1994). Moreover, in the same study, men who took up vigorous sports activities lowered their risk of death by 23 percent compared to those who remained sedentary (Paffenbarger et al., 1993). Similar favorable effects were observed in the Aerobics Center Longitudinal Study as men in the lowest quintile of fitness who improved their fitness to a moderate level, reduced mortality risk by 44 percent, an extent comparable to that achieved by smoking cessation (Blair et al., 1995). Results from observational and experimental studies of humans and laboratory animals provide biologically plausible insights into the benefits of regular physical activity on the delayed progression of several chronic diseases. The interrelationships between physical activity and cancer, cardiovascular disease, type 2 diabetes mellitus, obesity, and skeletal health are detailed in Chapter 3.

Table 12-9 shows seven prospective studies that associated varying ranges of leisure time energy expenditure (kcal/day or kcal/week) with the risk of chronic diseases and/or associated mortality. Assuming an average of 150 kcal expended per 30 minutes of moderate physical activity (Leon et al., 1987), the amount (minutes/day) of physical activity associated with risk was determined. The required amount of physical activity depended on the endpoint being evaluated. The minimum amount of physical activity that provided a health benefit ranged from 15 to 60 minutes/day. The amount of physical activity that provided the lowest risk of morbidity and/or mortality was 60 to greater than 90 minutes/day.

The proposed recommendation for a daily energy expenditure equivalent to that expended during 60 minutes of brisk walking is consistent with those recommendations in *Physical Activity and Health: A Report of the Surgeon General* (HHS, 1996). This recommendation is also consistent with Canada's "Physical Activity Guide to Healthy Living" (Health Canada, 1998), and the World Health Organization technical report on obesity (2000). Specifically, recommendation number 3 in Chapter 2 of the Surgeon General's report states: "Recommendations from experts agree that for better health, physical activity should be performed regularly. The most recent recommendations advise people of all ages to include a minimum of 30 minutes of physical activity of moderate intensity (such as brisk walking) on most, if not all, days of the week. It is also acknowledged that for most people, greater health benefits can be obtained by engaging in physical activity of more vigorous intensity or of longer duration."

Since the articulation of the HHS recommendation for a minimum 30 minutes/day of physical activity (HHS, 1996), evidence from epidemiological, observational and intervention studies continue to support the quoted statement above. Recently, the Women's Health Initiative Observational Study reported that 2.5 hours/week of vigorous exercise was associated with significantly reduced risk of cardiovascular disease in postmenopausal women (Manson et al., 2002). Moreover, they showed that more vigorous exercise was associated with an increased degree of protection. Conversely, physical inactivity, noted by prolonged sitting, was shown to be a significant risk factor for cardiovascular disease.

Similarly, reporting on treadmill evaluations of over 6,000 men studied over a 6-year period, Myers and coworkers (2002) concluded that "exercise capacity is a more powerful predictor of mortality among men than other established risk factors for cardiovascular disease." Recently, Kraus and colleagues (2002) demonstrated favorable effects of jogging for 6 months on blood lipoprotein profiles in overweight men and women, and the extent of changes were related to the amount and intensity of exercise.

Mental Health

Regular exercise has historically been associated with physical health and vigor (HHS, 1996), but exercise may also contribute to the sense of overall well-being and improved mood state. Mental health variables have

TABLE 12-9 Prospective Studies on the Level of Physical Activity in Reducing the Risk of Chronic Disease and Mortality

Reference	Subjects	Study Design[a]
Paffenbarger et al., 1978	16,936 Harvard male alumni, 35–74 y	Questionnaire on leisure-time physical activity, 6- to 10-y follow-up on risk of first heart attack
Paffenbarger et al., 1986	16,936 Harvard male alumni, 35–74 y	Questionnaire on leisure-time physical activity, 12- to 16-y follow-up on all-cause mortality
Leon et al., 1987	12,866 men, 35–57 y	Multiple Risk Factor Intervention Trial using Minnesota questionnaire of leisure-time physical activity, 7-y follow-up on CHD, other and all-cause mortality
Slattery et al., 1989	3,043 U.S. male railroad workers	Leisure-time physical activity questionnaire, 17- to 20-y follow-up on CHD and all-cause mortality
Helmrich et al., 1991	5,990 men, 39–68 y	Questionnaire on leisure-time physical activity, 14-y follow-up on development of type 2 diabetes
Haapanen et al., 1996	1,072 Finnish men, 35–63 y	Questionnaire on leisure-time physical activity, 10-y follow-up on the incidence of all-cause mortality and CVD mortality

Findings[b]	Analysis of Findings
The *minimum* amount of time associated with a reduction in a first heart attack was > 500 kcal/wk The *maximum* reduction in risk of a first heart attack was associated with leisure-time energy expenditure of 2,000–2,999 kcal/wk	The *minimum* amount of physical activity associated with a reduction in a first heart attack was > 15 min/d The *maximum* reduction in risk of a fatal heart attack was at 60–90 min/d
All-cause mortality declined steadily as ranges of energy expenditure from physical activity increased from 500–999 to 3,000–3,500 kcal/wk, beyond which rates slightly increased	The *minimum* amount of physical activity associated with reduced mortality was 30–60 min/d The amount of physical activity associated with *maximum* reduction in mortality was 85–100 min/d
	The *minimum* amount of physical activity associated with reduced CHD and all-cause mortality was 30–60 min/d. The amount of physical activity associated with the *maximum* reduced CHD and all-cause mortality was 30–60 min/d
The *minimum* amount of total leisure physical activity associated with reduced CHD, CVD and all-heart mortality was 251–1,000 kcal/wk Risk from death was the lowest when total leisure-time physical activity (light to moderate) was 1,001–1,999 kcal/wk	The *minimum* amount of total leisure time physical activity associated with reduced mortality was 10–30 min/d 30–60 min/d of total leisure time physical activity was associated with the *maximum* reduced risk of mortality
The *minimum* amount of mild/moderate physical activity associated with a reduced incidence of type 2 diabetes was 1,000–1,499 kcal/wk The incidence of type 2 diabetes declined as energy expenditure increased from < 500 (rr = 1) to > 3,500 kcal/wk (rr = 0.48)	The *minimum* range of mild/moderate physical activity associated with a reduced risk of type 2 diabetes was 30–45 min/d The amount of mild/moderate physical activity associated with the *maximum* reduction in type 2 diabetes was > 90 min/d
The *minimum* amount of physical activity associated with a reduced risk of CVD and all-cause mortality was 800–1,500 kcal/wk The amount of physical activity associated with the *maximum* reduction in all-cause mortality was > 2,100 kcal/wk and 800–1,500 kcal/wk for CVD mortality	The *minimum* amount of physical activity associated with reduced mortality was 23–45 min/d The amount of physical activity associated with the *maximum* reduction in all-cause mortality was > 60 min/d and 23–45 min/d for CVD mortality

continued

TABLE 12-9 Continued

Reference	Subjects	Study Design[a]
Rockhill et al., 2001	121,701 female nurses, 30–55y	Questionnaire on physical activity, 20-y follow-up of all-cause mortality, and death from various diseases

[a] CHD = coronary heart disease, CVD = cardiovascular disease.
[b] rr = relative risk.

been related to various forms of exercise, particularly acute and chronic aerobic exercise. The research evidence now supports stronger conclusions than presented in the *Physical Activity and Health: A Report of the Surgeon General* (HHS, 1996). The vast majority of review articles have concluded that acute or chronic aerobic exercise is related to favorable changes in anxiety, depression, stress reactivity, positive mood, self-esteem, and cognitive functioning (Anthony, 1991; Craft and Landers, 1998; Landers and Arent, 2001; Mutrie, 2000; North et al., 1990; Paluska and Schwenk, 2000; Salmon, 2001). Although one reviewer (Mutrie, 2000) has argued for a causal relationship between exercise and the reduction of clinical depression, others suggest that there are not enough clinical trial studies to support a causal interpretation (Landers and Arent, 2001). Examination of the meta-analyses indicates that the overall magnitude of the effect of exercise on anxiety, depression, stress reactivity, and cognitive functioning ranges from small to moderate, but in all cases, these effects are statistically significant (Landers and Arent, 2001).

These results are encouraging, but there is still much to learn before the relationship between physical activity and mental health can be fully understood. Recent reviews on endorphins (Hoffman, 1997), serotonin (Chaouloff, 1997), and norepinephrine (Dishman, 1997) have provided experimental evidence for potential mechanisms by which exercise can produce calming effects and mood enhancements.

Findings[b]	Analysis of Findings
The *minimum* amount of physical activity associated with a reduced risk of all-cause mortality and specific causes or mortality was 1–1.9 h/wk The *maximum* reduction in risk (rr = 0.71) of all-cause mortality was observed for those who expended > 7 h/wk of physical activity; those specific causes of death that were most affected were respiratory deaths (rr = 0.23) and noncancer, non-CVD, and nondiabetes deaths (rr = 0.46)	The *minimum* amount of physical activity associated with a reduced risk of mortality was 15–30 min/d A minimum amount of physical activity associated with the *maximum* reduction in mortality was 60 min/d

NOTE: 150 kcal = 30 min of a combination of light, moderate, and some vigorous physical activity (Leon et al., 1987).

BALANCE OF CARBOHYDRATE AND LIPID OXIDATION DURING EXERCISE AND RECOVERY

The balance of carbohydrate and lipid used by an individual during exercise depends mainly on relative intensity, or level of effort as related to the individual's maximal rate of oxygen consumption (Vo_2max) the greatest oxygen consumption that can be attained during an all out physical effort). In general, Vo_2max is related to body muscle mass and is a relatively constant value for a given individual but it can be altered by various factors, particularly aerobic training, which will induce a change of 10 to 20 percent. Thus, on an absolute basis, bigger individuals tend to have a larger Vo_2max (measured in liters of O_2 consumed/minute) than do smaller individuals. However, Vo_2max is also related to the size of the body and the heart. Hence, for purposes of comparison, Vo_2max is frequently considered in terms of mL/kg/min. Some examples are illustrative. An unfit man of average weight (70 kg) might have an absolute Vo_2max of 2.8 L/min, corresponding to 40 mL/kg/min (2.8 L/70 kg/min). If the man's resting metabolic rate (RMR) is 250 mL/min, he would be expected to be capable of 11.5 MET (40 mL/kg/min divided by 1 MET defined as 3.5 mL O_2/kg/min). However, a heart disease patient of the same body size might be capable of only a Vo_2max of 0.50 to 0.75 L/min, corresponding to 7 mL/kg/min (0.5 L/70 kg/min) to 10 mL/kg/min (0.75 L/70 kg/min). This would be equivalent to 2 (7 mL/kg/min divided by 3.5 mL O_2/kg/min) or 3 METs (10 mL/kg/min divided by 3.5 mL O_2/kg/min), while an Olympic-class middle distance runner of the same weight may be capable of achieving a

Vo_2max of 6 L/min, which is equivalent to 85 mL O_2/kg/min (6 L/70 kg/min), or 24 METs (85 mL O_2/kg/min divided by 3.5 mL O_2/kg/min).

Lipid is the main energy source in muscle and at the whole-body level during rest and mild intensity activity (Brooks and Mercier, 1994). As intensity increases, a shift from the predominant use of lipid to carbohydrate occurs. Figure 12-7 describes this crossover concept and, as can be seen in the figure, the relative use of fat is greatest at relatively low exercise intensities, particularly when individuals are fasting. Training slightly increases the relative use of fat as the energy source during low to moderate exercise intensities, particularly in the fasted state. In regard to the amount of fat oxidized, it must be considered that the energy output for a given percent of Vo_2max is proportionally higher (in this case 50 percent) in trained rather than in untrained cyclists. However, at relatively high power outputs, substrate use crosses over to predominant use of carbohydrate energy sources regardless of training state or recent carbohydrate nutrition.

To be used for energy generation, protein must first be degraded to amino acids before the carbon-hydrogen-oxygen skeleton can be used as an energy source through the pathways of carbohydrate and lipid metabolism, while the amino acid nitrogen is transferred and eliminated, primarily in the form of urea. The rate at which amino acids contribute to energy generation is fairly constant and does not increase nearly as much as glucose and fatty acid oxidation during periods of physical exertion. While the rate of oxidation of particular amino acids (e.g., leucine) may rise significantly during exercise, not all amino acids respond in the same way, and amino acids diminish in relative importance as fuels when power output rises during exercise (Brooks et al., 2000), providing only a small percentage of the energy used during physical activity (Brooks, 1987). Indeed, using amino acids as a major energy source would be wasteful, since protein is the most limited energy yielding nutrient. Beyond the overriding effect of relative exercise intensity, other factors such as exercise duration, gender, training status, and dietary history play important, but secondary, roles in determining the pattern of substrate utilization (Brooks et al., 2000). Therefore, the same general relationships among relative exercise intensity, duration, and pattern of substrate utilization hold for most persons, including endurance athletes.

Intensity of Physical Activity

Oxidation of lipid provides most of the energy (~ 60 percent) for noncontracting skeletal muscle and overall for the body at rest in people who have not eaten for 10 to 12 hours (i.e., postabsorptive conditions) (Brooks, 1997). Glucose released from the liver into the circulation provides the remainder of the energy for the body overall, particularly the brain, kidneys,

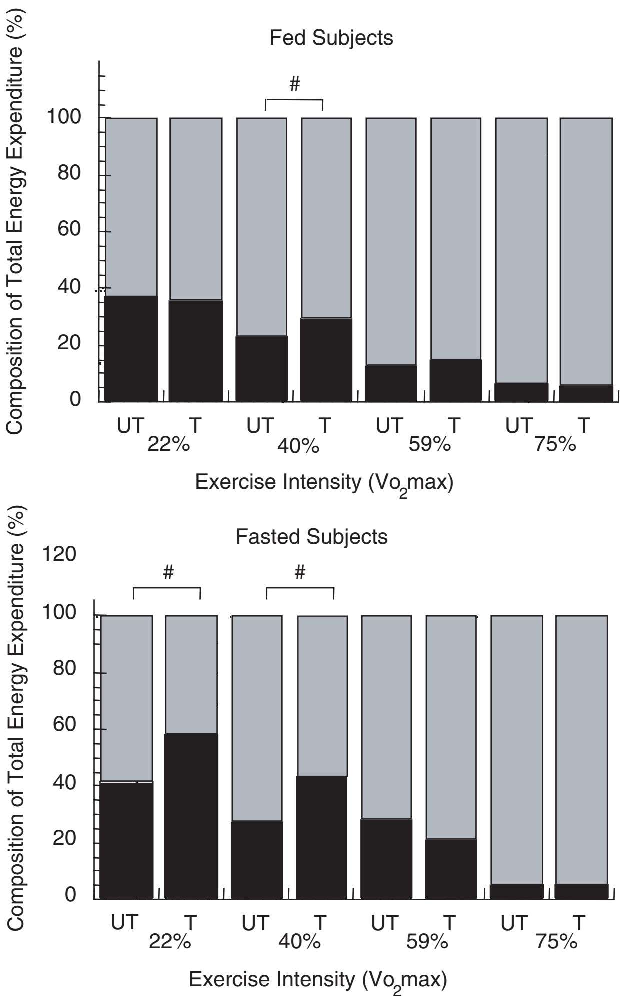

FIGURE 12-7 Illustration of the effects of relative exercise intensity, recent carbohydrate feeding, and training status on the relative use of carbohydrate (CHO) and lipid (black) energy sources as determined by indirect calorimetry. Untrained men (UT) and trained (T) male cyclists were studied after being recently fed (3–4 h after a 550-kcal meal [87% CHO, 11% protein, 2% fat]) or after an overnight (12-h) fast, during continuous cycling at graded relative exercise intensities over periods of 120 min (22% and 40% Vo_2max), 90 min (59% Vo_2max), and 45 min (75% Vo_2max). Exercise intensity expressed as a percentage of maximal oxygen consumption (Vo_2max), which averaged 39 and 58 mL of oxygen/min/kg body weight among the UT and T cyclists. $p < 0.05$ for #. Reprinted, with permission, from Bergman and Brooks (1999). Copyright 1999 by the American Physiological Society.

and blood. During mild exercise, the use of lipid increases, but if the level of effort increases, carbohydrate energy sources are used to a relatively greater extent (Figure 12-7). Peak rate of lipid oxidation is achieved at approximately 45 percent of Vo_2max. For exercises intensities greater than 50 percent of Vo_2max, the oxidation of free fatty acids declines in muscle, both as a percentage of total energy as well as on an absolute basis. In other words, there is crossover from prevalence of lipid oxidation at rest and during mild exercise to predominance of carbohydrate energy sources during moderate and greater efforts. The main carbohydrate energy source is muscle glycogen, and this is supplemented to some extent by glucose and lactate—glucose mobilized from the liver and lactate produced by muscle glycogen breakdown. If exercise persists beyond 60 to 90 minutes, lipid use will rise as carbohydrate fuel sources become depleted. In this case, the intensity of exercise must drop because of the depletion of muscle glycogen, decreasing levels of blood glucose, and other fatiguing consequences of the effort (Graham and Adamo, 1999).

Dietary carbohydrate is relatively rapidly assimilated compared to fat and protein, thus raising blood glucose and insulin levels. The increments in blood glucose and insulin in response to carbohydrate intake are less in trained than in untrained individuals (Dela et al., 1991; King et al., 1987). Still, carbohydrate feeding stimulates carbohydrate oxidation, raising the respiratory exchange ratio ($RER = R = Vco_2/Vo_2$) in all individuals. Hence, as shown in Figure 12-7 for fed individuals, crossover to predominant carbohydrate oxidation occurs already during mild (22% Vo_2max) exercise, even in trained individuals, if they have recently consumed carbohydrates.

Duration of Physical Activity

Within seconds after initiation of even mild exercise, muscle glycogen stores are mobilized to provide energy for muscle work. Over the next few minutes, as circulatory oxygen supply rises to meet demand and muscle cell energy homeostasis is restored, the use of muscle glycogen subsides and free fatty acids (FFA) as well as lipid previously stored within muscle cells (intramuscular triacylglycerol) are activated and used. After the transition period in which glycogen is primarily used, the fuel mix used during sustained mild intensity exercise returns toward the mix used at rest, in which FFA predominate. Such mild intensities correspond to easy walking and household chores. As exercise intensity increases, FFA oxidation increases, achieving a peak at about 45 percent Vo_2max; thereafter, use of carbohydrate fuel sources (i.e., muscle glycogen, blood glucose, lactate) rises exponentially and lipid oxidation declines (Figure 12-7). Depending on the person, the change from fat to carbohydrate dependence occurs at different levels of exertion. In some individuals, this may happen during activities such as brisk walking. When labored breathing accompanies exercise, crossover to carbohydrate dependence has generally occurred.

In most cases, relationships between activity duration and intensity will be inversely related—harder intensity physical activities will necessarily be of less duration than easier ones. Extreme effort is made possible in part by the use of preformed high-energy bonds in the form of creatine-phosphate, in addition to energy generation by glycogen and glucose catabolism, with very little use of fat, leading to fatigue within seconds or minutes. Thus, the energy flux rate will be high, but total energy liberated small. In contrast, activities of mild to moderate intensity, performed over periods of hours, can result in large increments of energy expenditure with a substantial contribution coming from lipid stores (Brooks et al., 2000). Therefore, in order to use physical activity to enhance body fat utilization, sustained activity that causes substantial increases in energy expenditure is more important than the peak rate of substrate oxidation. Even in highly fit athletes, glycogen reserves will become largely depleted after maintaining high rates of exertion for several hours, so that increasing amounts of lipid will be oxidized. As a result of such physical activity, increased lipid oxidation will also take place during recovery from exercise (Chad and Quigley, 1991; Kiens and Richter, 1998).

Gender

In general, metabolic responses of women and men are similar, but women oxidize more lipid than men during exercise and when performing a task at a given level of intensity (Friedlander et al., 1998a, 1998b, 1999; Tarnopolsky et al., 1990). Paradoxically, women depend more on blood glucose and less on muscle glycogen than do men. The effects of menstrual variations on substrate utilization are under investigation, but the effects are likely to be small, because estrogen and progesterone appear to have antagonistic effects on substrate utilization (Campbell et al., 2001; Suh et al., 2002). In contrast to the effects of menstrual cycle variations in endogenous ovarian sex steroids, high levels of exogenous synthetic ovarian steroid analogs, such as contained in oral contraceptives, cause a mild insulin resistance and decrease use of blood glucose in women at rest (Yen and Vela, 1968). Consequently, men and women may possibly differ subtly in patterns of substrate utilization during physical activity, but overall patterns of carbohydrate and lipid use are similar. The effect of menopause on substrate utilization during exercise has not been studied in sufficient detail to establish if it leads to significant changes in substrate utilization. However, changes in body fat content and distribution after menopause suggest that patterns of activity and energy substrate utilization change after menopause (Poehlman et al., 1995).

Age

Maximal oxygen consumption is typically stable in the third decade of life, but then declines approximately 1 percent/year (0.5 ml/kg/min) after age 30 (Raven and Mitchell, 1980). This age-related decline is associated with the decline in muscle mass and maximal heart rate that decreases approximately 1 beat/min/year (Suominen et al., 1977). As a result, fat oxidation during physical activity is decreased and carbohydrate oxidation is increased in elderly adults (Sial et al., 1996). Recognizing that Vo_2max declines with age, any given task is likely to be accomplished at relatively greater exercise intensity, and consequently greater dependence on carbohydrate-derived energy sources. However, if relative exercise intensity is considered, many older individuals are capable of prolonged exercise at 50 to 60 percent of Vo_2max, and accordingly can oxidize significant quantities of carbohydrate and lipid (Sial et al., 1996) to favorably affect physiological systems as well as change energy balance and body composition.

Sedentary older individuals who become active through resumption of outdoor activities, gymnasium exercises, or other forms of occupational or recreational activities respond much like younger individuals (Hagberg et al., 1989; Hagerman et al., 2000). While the extent of adaptation is obviously limited in older ages, relative changes in muscle strength and aerobic capacity can be comparable or even greater than in younger adults (Hagberg et al., 1989; Hagerman et al., 2000). It must be noted that acute illness resulting in bed rest can result in a notable (~10 percent) decline in Vo_2max in 1 week, but the decline is transient and recovery occurs in a similar time frame after resumption of regular physical activities (Greenleaf and Kozlowski, 1982).

Growth and Development

In general, in children maximal oxygen consumption is higher per unit of body weight and higher in boys than girls, although the difference is small until the pubertal growth. The growth spurt usually comes earlier in girls than boys, so maximal oxygen consumption in 12- to 13-year-old girls may match or surpass that of age-matched boys. However, in boys, puberty results in much larger increments in total muscle mass, blood volume, and lung and heart size than girls. Girls acquire more fat mass than do boys and boys frequently lose body fat during the pubertal growth spurt. Consequently, puberty results in a large increment in Vo_2max whether expressed in absolute or relative terms in boys. In girls, the relative rise in Vo_2max during the pubertal growth spurt is smaller, since the absolute increase in muscle mass is less and the relative rise in fat mass (FM) is greater than in boys. Regular endurance exercise can result in a significant increment in the Vo_2max of boys and girls (Brown et al., 1972; Mahon and Vaccaro, 1989, 1994; Vaccaro and Clarke, 1978) as well as in adults (Gallo et al., 1989; Maciel et al., 1985; Tabata et al., 1996).

It is generally assumed that the pattern of substrate utilization in children during rest and exercise is similar to that in adults. However, the data on effect of exercises of graded intensities and duration on the balance of substrate utilization in children are scarce. Compared to adults, the capacity of glycogenolysis in non–fully differentiated skeletal muscle is less in children, and they are generally less capable of speed and power-related activities (Krahenbuhl and Williams, 1992).

Physical activity levels in children vary widely, as they are capable of large amounts of spontaneous, self-directed physical activity (Blaak et al., 1992). The effects of exercise on body composition in children are likely greater than in adults, because of the much greater levels of growth hormone in children (Borer, 1995). Because growth hormone has both anabolic (tissue-building) and lipolytic (fat-mobilizing) effects (Bengtsson et al., 1990), it is not surprising that physically active children are stronger and leaner than their obese counterparts (Owens et al., 1999).

Results from the 1999 Youth Risk Behavior Study (CDC, 2000) indicate that only 29 percent of high school students attend physical education classes daily, and participation declines to 20 percent by grade 12 (Table 12-10). Furthermore, not only is there a decline in the frequency of physical education participation by high school students, but there is also a steady decline in the vigor of participation, as estimated by length of time engaging in physical activity/exercise during class.

PHYSICAL FITNESS

Endurance (Aerobic) Exercise

Traditionally, the types of activities recommended for cardiovascular fitness are those of a prolonged endurance nature, such as bicycling, hiking, jogging, and swimming. Sometimes the word "aerobic" is used as an alternative to describe such activities because integrated functions of lungs, heart, cardiovascular system, and associated muscles are involved. Because of the energy demands associated with aerobic activity, such activities have the potential to impact body fat mass (FM) (Grund et al., 2001). By decreasing FM and preserving fat free mass (FFM), prolonged mild to moderate intensity endurance exercise can change body composition.

TABLE 12-10 Percentage of Students in Grades 9 Through 12 Who Reported Enrollment in Physical Education Classes, Attendance in Physical Education Classes Daily, and Spending More Than 20 Minutes Exercising During Class, by Demographic Group[a]

Demographic Group	Enrolled in Physical Education Classes	Attended Physical Education Classes Daily	Exercised More Than 20 Min per Class[b]
Overall total	56.1 (48.9–63.3)	29.1 (19.7–38.5)	76.3 (72.6–80.0)
Gender			
Females	51.5 (43.8–59.2)	26.3 (17.3–35.3)	69.6 (65.6–73.6)
Males	60.7 (53.7–67.7)	31.9 (21.9–41.9)	82.1 (77.5–86.7)
Race/ethnicity			
White, non-Hispanic			
Total	56.1 (46.3–65.9)	28.3 (15.5–41.1)	78.7 (74.3–83.1)
Females	51.7 (40.5–62.9)	25.8 (13.3–38.3)	72.4 (67.0–77.8)
Males	60.2 (51.0–69.4)	30.8 (17.5–41.1)	83.8 (79.3–88.3)
Black, non-Hispanic			
Total	52.9 (39.1–66.7)	29.2 (19.3–39.1)	67.8 (64.3–71.3)
Females	47.1 (34.1–60.1)	25.5 (17.0–34.0)	55.8 (50.2–61.4)
Males	59.2 (43.4–75.0)	33.1 (20.4–45.8)	78.4 (74.3–82.5)
Hispanic			
Total	59.3 (52.3–66.3)	40.4 (31.5–49.3)	75.5 (70.5–80.5)
Females	53.6 (44.5–62.7)	36.2 (25.9–46.5)	70.8 (63.9–77.7)
Males	65.1 (58.1–72.1)	44.6 (35.9–53.3)	79.6 (73.5–85.7)
Grade in school			
9th			
Total	78.9 (73.0–84.8)	42.1 (29.6–54.6)	78.7 (74.5–82.9)
Females	75.6 (69.0–82.2)	40.3 (28.1–52.5)	72.5 (65.6–79.4)
Males	82.3 (76.4–88.2)	44.0 (30.8–57.2)	84.4 (80.1–88.7)
10th			
Total	60.9 (49.0–72.8)	30.4 (20.7–40.1)	75.1 (69.9–80.3)
Females	56.6 (43.1–70.1)	27.9 (17.7–38.1)	70.2 (64.6–75.8)
Males	65.3 (54.1–76.5)	32.8 (22.6–43.0)	79.4 (72.8–86.0)
11th			
Total	40.7 (31.5–49.9)	20.0 (11.7–28.3)	75.7 (70.9–80.5)
Females	36.8 (27.6–46.0)	16.6 (8.2–25.0)	68.0 (61.2–74.8)
Males	44.6 (34.5–54.7)	23.5 (15.0–32.0)	82.0 (76.0–88.0)
12th			
Total	36.6 (25.6–47.6)	20.1 (10.2–30.0)	73.4 (63.3–83.5)
Females	29.4 (17.6–41.2)	16.6 (8.5–24.7)	60.1 (51.9–68.3)
Males	43.8 (32.7–54.9)	23.6 (11.4–35.8)	82.3 (71.1–93.5)

[a] 95% confidence interval.
[b] Among students enrolled in physical education classes.
SOURCE: CDC. 2000. 1999 Youth Risk Behavior Survey.

Resistance Exercise and General Physical Fitness

Initial efforts by health professionals to reduce FM involved endurance exercise protocols mainly because of the large impact on total energy expenditure and links to coronary heart disease risk amelioration. More recent efforts using resistance exercise training, or combinations of resistance and endurance exercises, have been tried to maintain the interest of participants as well as to positively affect body composition through stimulation of anabolic stimuli (Grund et al., 2001). Practitioners of speed, power, and resistance exercises can change body composition by means of the muscle-building effects of such exertions. Moreover, exercises that strengthen muscles, bones, and joints stimulate muscle and skeletal development in children, as well as assist in balance and locomotion in the elderly, thereby minimizing the incidence of falls and associated complications of trauma and bed rest (Evans, 1999). While resistance training exercises have not yet been shown to have the same effects on risks of chronic diseases, their effects on muscle strength are an indication to include them in exercise prescriptions, in addition to activities that promote cardiovascular fitness and flexibility.

Supplementation of Water and Nutrients

As noted earlier, carbohydrate is the preferred energy source for working human muscle (Figure 12-7) and is often utilized in preference to body fat stores during exercise (Bergman and Brooks, 1999). However, over the course of a day, the individual is able to appropriately adjust the relative uses of glucose and fat, so that recommendations for nutrient selection for very active people, such as athletes and manual laborers, are generally the same as those for the population at large. With regard to the impact of activity level on energy balance, modifications in the amounts, type, and frequency of food consumption may need to be considered within the context of overall health and fitness objectives. Such distinct objectives may be as varied as: adjustment in body weight to allow peak performance in various activities, replenishment of muscle and liver glycogen reserves, accretion of muscle mass in growing children and athletes in training, or loss of body fat in overweight individuals. However, dietary considerations for active persons need to be made with the goal of assuring adequate overall nutrition.

Following the recently released joint position statement of the American College of Sports Medicine, American Dietetics Association, and Dietitians of Canada (ACSM et al., 2000), water and fluids containing carbohydrates and electrolytes may be consumed immediately prior to, during, and after physical activity. For instance, a collegiate swimmer arriving on an empty stomach at the training site should be provided with fluids during and immediately after training as well as food after training. Similarly, following competition or training for competition, athletes should rehydrate and consume a high carbohydrate meal (ACSM, 2000). For the healthy individual, the amount and intensity of exercise recommended is unlikely to lead to glycogen depletion, dehydration, or water intoxication. Nonetheless, timing of post-exercise meals to promote restoration of glycogen reserves and other anabolic processes can benefit resumption of normal daily activities.

ADVERSE EFFECTS OF EXCESSIVE PHYSICAL ACTIVITY

Adverse Effects

Overuse Injuries

Physical exercise has the potential to cause overuse injuries to muscles, bones, and joints as well as injuries caused by accidents. Additionally, preexisting conditions can be aggravated upon initiation of a physical activity program, and chronic, repetitive activities can result in injuries. For instance, running can result in injuries to muscles and joints of the lower limbs and back, swimming can cause or irritate shoulder injuries, and cycling can cause or worsen problems to the hands, back, or buttocks. Fortunately, the recommendation in this report to accumulate a given amount of activity does not depend on any particular exercise or sports form. Hence, the activity recommendation can be implemented in spite of possible mild, localized injuries by varying the types of exercise (e.g., walking instead of jogging). Recalling the dictum of "do no harm," the physical activity recommendations in this report are intended to be healthful and invigorating. Activity-related injuries are always frustrating and often avoidable, but they do occur and need to be resolved in the interest of long-term general health and short-term physical fitness.

Dehydration and Hyperthermia

Physical activity results in conversion of the potential chemical energy in carbohydrates and fats to mechanical energy, but in this process most (~ 75 percent) of the energy released appears as heat (Brooks et al., 2000). Evaporative heat loss from sweat is the main mechanism by which humans prevent hyperthermia and heat injuries during exercise. Unfortunately, the loss of body water as sweat during exercise may be greater than what can be replaced during the activity, even if people drink ad libitum or are on a planned diet. Hence, exercise may result in dehydration that increases the stress and relative difficulty of subsequent activity. This can be aggravated by environmental conditions that increase fluid losses, such as heat, humidity, and lack of wind (Barr, 1999). Therefore, as already described, people should consume water before, during (if possible), and after exercise (ACSM et al., 2000).

A weight loss of 1 to 2 percent of body weight on a day following exercise cannot be attributed to a loss of body fat, but reflects some degree of hypohydration that needs to be compensated for by the consumption of fluids (ACSM et al., 2000). Individuals who have lost more than 2 percent of body weight are to be considered physiologically impaired (Naghii, 2000) and should not exercise, but rehydrate.

Hypothermia

Hypothermia can result from water exposure and during winter sports. Even exposure to cool, damp environments can be dangerous to inadequately clothed and physically exhausted individuals. Accidental immersion due to capsizing of boats, poor choice of clothing during skiing, change in weather, or physical exhaustion leading to an inability to generate adequate body heat to maintain core body temperature can all lead to death, even when temperatures are above freezing. Prevention of hypothermia and its treatment are beyond this report; however, hypothermia is unlikely to accrue from attempts to fulfill the physical activity recommendation. Because water and winter sports are gaining popularity and do provide means to enjoyably follow the physical activity recommendation, safe participation in such activities needs special instruction and supervision.

Cardiac Events

While regular physical activity promotes cardiovascular fitness and reduces risks associated with cardiovascular diseases (CVD), heavy physical exertion can trigger the development of arrhythmias or myocardial infarctions (Mittleman et al., 1993; Thompson, 1982; Willich et al., 1993) or, in some instances, can lead to sudden death (Kohl et al., 1992; Koplan, 1979; Siscovick et al., 1984; Thompson, 1982). Thus, while it is true that compared to the population at large, individuals who exercise regularly have reduced risk of CVD and sudden cardiac death, there is a transient increase in risk in this group during and immediately after vigorous exercise (Kohl et al., 1992; Siscovick et al., 1984). However, Manson and colleagues (2002) recently reported that both walking and vigorous activity were associated with marked reductions in the incidence of cardiovascular events.

Female Athlete Triad

Although loading the skeleton through resistance (e.g., weight training, weight-bearing exercises) and impact activities (e.g., jumping) increases bone mineral density (BMD) (Fuchs et al., 2001; Welten et al., 1994), athletic women who undereat and/or overtrain can develop a condition, or cluster of conditions (disordered eating, amenorrhea, and osteoporosis) termed the "female athlete triad" (ACSM, 1997; Thrash and Anderson, 2000; West, 1998). In this triad, disordered eating and chronic energy deficits can disrupt the hypothalamic-pituitary axis, leading to loss of menses, osteopenia, and premature osteoporosis (Loucks et al., 1998), increasing the possibility of hip, spine, and forearm fractures. While dangerous in themselves, skeletal injuries can predispose victims to a cascade of events including thromboses, infections, and physical deconditioning.

Prevention of Adverse Effects

The possibility that exercise can result in overuse injuries, dehydration, and heart problems has been noted above. Consequently, a prudent approach to initiating physical activity or exercise by previously sedentary individuals is recommended. Men over 40 years of age and women over 50 years of age, those with pre-existing conditions, known or suspected risk factors or symptoms of cardiovascular and other chronic diseases (physical inactivity being a known risk factor) should seek medical evaluation as well as clinical exercise testing, clearance, and advice prior to initiating an exercise program (ACSM, 2000). The evaluation should include a stress electrocardiogram and blood pressure evaluation. Ideally, respiratory measurements should be performed to evaluate Vo_2max.

For all individuals initiating an exercise program, emphasis should be placed on the biological principle of stimulus followed by response. Hence, easy exercises must be performed regularly before more vigorous activities are conducted. Similarly, exercise participants need to rest and recover from previous activities prior to resuming or increasing training load. Also, as already noted, conditions of chronic soreness or acute pain and insomnia could be symptoms of over-training. Hence, activity progression should be discontinuous with adequate recovery periods to minimize chances of injury and permit physiological adaptations to occur. Those adaptations are elicited during exercise but occur during recovery. Thus, physical activity recommendations for healthful living, whether a minimum of 30 minutes for most days, as recommended in the Surgeon General's report (HHS, 1996), or 60 minutes a day, should not be construed as the starting point for an adult wishing to change from a sedentary lifestyle to a more active form of living. Depending on the individual, as little as 5 to

10 minutes a day may represent an appropriate starting point, undertaken under professional supervision for those with cardiovascular risk or orthopedic problems. Attention also needs to be given to stretching and strengthening activities as part of the physical activity core to healthful living.

RESEARCH RECOMMENDATIONS

- More information is needed on the effect of exercise (i.e., endurance, resistance, other), frequency, intensity, and duration on body fatness in young and elderly adults and children.
- More information is needed on the effects of exercise on substrate utilization and the roles of various energy depots (liver glycogen, muscle glycogen, adipose triacylglycerol, intramuscular triacylglycerol) in exercise and recovery in children, adults, and the elderly.
- Research is needed to determine whether the timing of meals and exercise can be used to optimize changes in, or to maintain favorable Body Mass Indexes and body compositions of moderately and very active individuals.
- Research is needed to determine whether there are dietary compositions that optimize accretion of lean tissue in growing children and physically active adults.
- More information is needed to identify the mechanisms by which acute and chronic physical activity alter substrate utilization and body composition.
- Efforts need to be undertaken to develop reliable, noninvasive, and clinically appropriate measurements of body composition, cardiovascular function, and physical fitness.
- Efforts should be directed at developing practical, yet reliable methods to assess habitual levels of physical activity.

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